Report No. CG-D-11-95

SHIPPING STUDY

The Role of Shipping in the Introduction of Nonindigenous Aquatic Organisms to the Coastal Waters of the United States (other than the Great Lakes) and an Analysis of Control Options

The National Sea Grant College Program/Connecticut Sea Grant Project R/ES-6

James T. Carlton
Donald M. Reid
Henry van Leeuwen

Maritime Studies Program
Williams College - Mystic Seaport
75 Greenmanville Avenue
Mystic, CT 06355

FINAL REPORT
April 1995

This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for:

U.S. Coast Guard
Research and Development Center
1082 Shennecossett Road
Groton, Connecticut 06340-6096

and

U.S. Department Of Transportation
United States Coast Guard
Office of Engineering, Logistics, and Development
Washington, DC 20593-0001

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.

The United States Government does not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

The contents of this report reflect the views of the Coast Guard Research & Development Center. This report does not constitute a standard, specification, or regulation.

W. E. Colburn, Jr.
Technical Director, Acting
United States Coast Guard
Research & Development Center
1082 Shennecossett Road
Groton, CT 06340-6096

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CG-D-11-95		

4. Title and Subtitle	5. Report Date
SHIPPING STUDY - The Role of Shipping in the Introduction of Non-indigenous Aquatic Organisms to the Coastal Waters of the United States (other than the Great Lakes) and an Analysis of Control Options	April 1995
	6. Performing Organization Code
7. Author(s) James T. Carlton, Donald M. Reid, Henry van Leeuwen	8. Performing Organization Report No. R&DC 17/92
9. Performing Organization Name and Address Maritime Studies Program Williams College - Mystic Seaport 75 Greenmanville Avenue Mystic, CT 06355	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTCG-91-F-HMR337-1
12. Sponsoring Agency Name and Address U.S. Coast Guard Research and Development Center 1082 Shennecossett Road Groton, Connecticut 06340-6096 Department of Transportation U.S. Coast Guard Office of Engineering, Logistics, and Development Washington, D.C. 20593-0001	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

This report was mandated by U.S. Public Law 101-646 (29 November 1990).

16. Abstract

This study investigated the extent to which shipping contributes to the introducton of nonindigenous species into U.S. waters; potential options for controlling such introductions; and the issue of whether this problem is of regional or national concern. Data on shipping traffic patterns and ballast water management practices were collected, and estimates were made of the amount and sources of ballast water released in or near U.S. waters. The feasibilities of various options for controlling ballast water-mediated invasions were examined via consultations with experts in various fields and investigation into capabilities of products on the market. Recommendations include potential strategies for managing/reducing the risk of nonindigenous species invasions.

17. Key Words	18. Distribution Statement
ballast water exotic species nonindigenous ballast water exchange ballast water control shipping study zebra mussel ballast sediments invasions	Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. SECURITY CLASSIF. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED		

Form DOT F 1700.7 (8/72) Reproduction of form and completed page is authorized

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (WEIGHT)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (EXACT)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (WEIGHT)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (EXACT)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

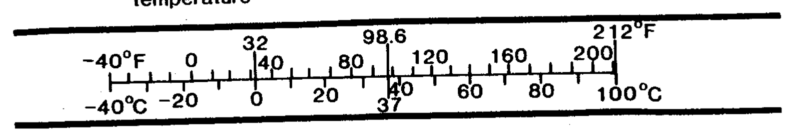


TABLE OF CONTENTS

<u>Note:</u>
To highlight **selected** tables, figures, and boxes in this Report, abbreviated titles are given below; full titles and complete listings are given in the Lists of Tables, Figures, and Boxes (pages xii-xiii).

Appendices (continued)

LIST OF TABLES

LIST OF FIGURES

LIST OF BOXES

NABISS PERSONNEL

1991 - 1992

James T. Carlton	Principal Investigator
Donald M. Reid	Project Manager and Research Associate
Henry van Leeuwen	Research Associate
Katrina Bercaw	Administrative Assistant (part-time)
Ellen Anderson	Research Assistant (part-time)
Kristine Helbling	Research Assistant (part-time)
Laurie Wilson	Research Assistant (part-time)

EXECUTIVE SUMMARY

1. The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (Public Law 101-646) established a "National Ballast Water Control Program" which in turn mandated "Studies on Introduction of Aquatic Nuisance Species by Vessels." One of these studies is the Shipping Study, defined as follows: "a study to determine the need for controls on vessels entering waters of the United States, other than the Great Lakes, to minimize the risk of unintentional introduction and dispersal of aquatic nuisance species in those waters. The study includes an examination of -- (A) the degree to which shipping may be a major pathway of transmission of aquatic nuisance species in those waters; (B) possible alternatives for controlling introduction of those species through shipping; and (C) the feasibility of implementing regional versus national control measures."

2. The Shipping Study commenced in December 1991 in the laboratory of Dr. James T. Carlton, at the Williams College - Mystic Seaport Maritime Studies Program in Mystic, Connecticut. It was completed in April 1993. The study assumed the working name of the "National Biological Invasions Shipping Study" or NABISS, to address the three study elements listed above.

3. To address the above elements, we sought to address ballast water and port operations by visits, with U.S. Coast Guard cooperation, to selected major U.S. ports and by vessel boardings in these ports, and by a cooperative effort with United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) inspectors. We determined actual ballast carried versus ballast capacity, and a wide range of other data on routine ballasting, deballasting, and exchanging operations in time and space. We also sought, by using these and U.S. Customs/U.S. Census data, to estimate amounts of ballast water arriving in United States ports, and the origin of this water.

   We assessed ballast patterns in ten major commercial, hydrographic and biogeographic regions of the United States, as follows: (1) the Gulf of Maine, (2) the mid Atlantic, (3) the south Atlantic, (4) the eastern Gulf of Mexico, (5) the western Gulf of Mexico, (6) southern California, (7) northern California, (8) the Pacific Northwest, (9) Alaska, and (10) the Hawaiian Islands. Final port selection was based upon vessel traffic volume derived from U.S. Bureau of Census data. Twenty-two ports were visited, and vessels were boarded in 21 of these. Thus, five of the six U.S. coastlines were surveyed in this study (the Great Lakes are omitted by definition of the Shipping Study). In all we spoke, wrote, and worked with over 500 persons in international, national, state, and local agencies, institutions, universities, and industry. The range of dispersal mechanisms associated with shipping, and the resulting invasions in U.S. waters (particularly for ballast water associated species), were determined from NABISS vessel interviews and from literature, records, and personal observations, gathered and obtained by J. Carlton from 1962 to 1992.

4. The historical role of vessels as dispersal agents of freshwater, brackish water, and saltwater organisms is not well known. While the dispersal of aquatic organisms by ships commenced many centuries ago, reliable scientific distributional data on most of these organisms date only from the 20th century. As a result, many freshwater and marine biogeographers and systematists have classically viewed, and continue to view, many

distributions of plants and animals as "natural" if clear evidence of human-altered distribution patterns is lacking.

5. There have been and are hundreds of types of watercraft operating upon the world's canals, rivers, lakes, and oceans. Vessels ranging from rafts, dugouts, skiffs, and canoes to bulk carriers, oil tankers, and aircraft carriers are capable of transporting organisms from one body of water to another and from one continent to another. There are three major divisions: **Passenger vessels**, including passenger liners, ferries, and excursion boats, **cargo vessels**, including bulk carriers, container ships, and tankers, and **specialized vessels**, including barges, fishing vessels, and semisubmersible exploratory drilling platforms. A ship may be viewed as a "biological island" with organisms occurring on the outside, on the inside, and aboard the vessel.

Fouling organisms ("biofouling") occur on the hull, rudder, and propeller of modern vessels. Hull surfaces historically developed massive fouling communities, with layers of seasquirts, hydroids, and seaweeds a third of a meter or more thick. Such communities on ships appear to be rare now. Since World War II, heavily fouled barges may represent the modern-day analogue of older fouled ships. Boring organisms attack wooden structures below the low tide line (on fixed structures) and below waterline (on floating structures, such as wood floats and vessels). Wood borers include shipworms (which are worm-shaped bivalve mollusks related to clams and mussels) and tiny isopod crustaceans known as gribbles. Until the end of the 19th century, shipworms and gribbles were globally distributed by shipping. Remaining wooden vessels at the end of the 20th century include historic vessels (those in the water) at maritime museums, tall ships still actively sailing, wooden-hulled naval minesweepers, and many smaller fishing and recreational vessels. Wooden yachts infected with shipworms in tropical waters may carry such species north to colder waters, and infestations may result within the thermal effluents of power plants. Thus tropical shipworms have appeared in the warm-water effluents of power plants in Barnegat Bay, New Jersey and in Long Island Sound at Waterford, Connecticut. The exterior of vessels has thus historically provided perhaps the longest term, most fundamental vector for the dispersal of marine organisms.

The modern-day manifestation and importance of this phenomenon are difficult to assess for several reasons: (1) changes in shipping over the past century (discussed below) would suggest that the predominance of hull fouling communities may have declined, (2) there are few modern post-transport studies of ship-fouling communities, and (3) there is considerable difficulty in distinguishing the role of ship fouling from ship ballast water as the effective dispersal agent for some species. Changes in shipping relative to the role of vessels in transporting marine organisms include *increased vessel speeds, decreased port residency, increased use and efficacy of toxic antifouling paints, and increased frequency of hull cleaning.* However, other phenomena suggest that ship-mediated dispersal of fouling organisms may still occur on a regular basis. Fouled, slow-moving vessels and structures such as barges and floating dry docks still move across the world's oceans; certain fouling organisms have evolved a resistance to copper-based antifouling paints and greater vessel speeds may decrease mortalities of estuarine organisms in the open ocean. These and other factors suggest that fouled ship bottoms and sea chests could still play an important role in the introduction of exotic species to American shores.

6. For all modern ocean-going vessels, ballast is water taken aboard to stabilize the vessel at sea and for a variety of other purposes. The type of water ballasted is whatever water the vessel is in at the time of ballasting. Water may be fresh (0.5 parts per thousand (o/oo) dissolved salts or less), brackish (salt levels ranging from 0.5 to 30 o/oo) or salt (30 o/oo or greater). Most ballast water will naturally contain living organisms and varying amounts (loads) of dissolved and suspended organic and inorganic compounds -- in short, whatever is in the water under the ship at the time of ballasting. Regular transoceanic and interoceanic use of ballast water commenced in the 1880s, although it is probable that it was not until during and after World War II that ballast water in appreciable volumes began to be moved around the world.

7. Ballast water is pumped aboard a vessel from several meters below the water line with dedicated ballast pumps. The same pump and the same external hull openings are used to take water into (fill or ballast) and remove (discharge or deballast) water from a vessel. The ballast intake is covered with a steel plate (a grate or strainer) with numerous holes of 1.0 to 1.5 cm diameter. Water may be gravitated in or out of a particular tank or hold. Many container ships have what may be the most advanced computer-interfaced ballasting operations of any modern commercial seagoing vessel, with ballasting requirements being automatically determined based upon changing cargo loads. A vessel may have water from multiple sources, unmixed and mixed within the ship, with different water in different tanks. Biologically, this translates to the vessel potentially accumulating organisms from multiple ballastings at many sites. Container ships represent perhaps one of the best examples of the constant -- virtually daily -- movements of ballast water, typically taking up and discharging some quantity of water, in a "Johnny Appleseed" ("Johnny Clamseed") fashion, wherever they go. The movement and release patterns of ballast water are such that no coastal sites, whether they receive direct shipping or not, are immune to ballast-mediated invasions.

8. Water is carried by a vast variety of vessels and held in an impressive variety of tanks or holds. The advent of *segregated* and *dedicated* ballast tanks came about through national and international efforts to reduce the discharge of oily ballast in the ocean. Segregated ballast tanks are those in which only water is carried; these always have separate ballast piping. Dedicated ballast tanks are unaltered cargo tanks used exclusively for ballast. *Permanent* or *semi-permanent* ballast may be water ballast that is rarely changed.

9. Ballast capacity can range from hundreds of gallons in sailing boats and fishing boats to tens of millions of gallons in commercial cargo carriers. An ore carrier travelling from Europe to Brazil may carry up to 120,000 MT (about 32,000,000 gallons) of ballast water. Tankers with similar ballast capacity travel to Valdez. Large cargo vessels in the Australian trade can have ballast water capacities of 140,000 tons (about 37,000,000 gallons). A large oil tanker travelling from North America back to the Persian Gulf could have 280,000 tons of ballast water (in ballast and in cargo tanks) -- or about 74,000,000 gallons of water.

10. Vessels are said to be *in ballast* when they have ballast water and no cargo aboard. A vessel is *with ballast* when cargo and some ballast water are aboard. Vessels on their "ballast leg" normally carry the most ballast water. Vessels on their "cargo leg" may also have ballast water, with amounts varying relative to the needs to provide stability for the vessel. Inbound vessels that have released their ballast water prior to or during cargo

loading, and outbound vessels with full cargo loads, may have sufficiently little ballast on board that the mariner would report a ballasting condition of "No Ballast on Board" even when small amounts remain. While the amounts of unpumped or unpumpable water, or of trim water in a loaded vessel, may be only in the hundreds or thousands of tons, from the point of view of a marine biologist these volumes of water (tens of thousands to hundreds of thousands of gallons) may still be of sufficient quantity to support an abundant and diverse assemblage of living organisms. It may be taken as a general rule that, with rare exception, virtually all vessels have some ballast water aboard all of the time.

11. U. S. Customs and port records do not normally record the amounts of ballast water carried when vessels are "in ballast", and usually do not record the presence of ballast water at all when vessels are "with ballast". We refer to vessels in ballast, as reported in government records, as having *acknowledged ballast*; vessels with ballast have *unacknowledged ballast*. *Cryptic ballast* is thus unacknowledged ballast, unpumpable ballast, reported "no ballast on board" when there is water present, and ballast water on board vessels not recorded by government records, such as military vessels.

12. Almost all vessels ever sampled in Canadian, Australian, and U.S. studies have been found to contain living organisms. There is now no question that ballast water provides a viable in-transit habitat for a wide variety of freshwater, brackish water, and marine organisms. The potential diversity of "ballastable biota" is often not fully appreciated. Virtually all aquatic organisms that can occur in the water column, actively or passively, or be stirred up from bottom sediments, or rubbed off harbor pilings, could be ballasted into a vessel. Bacteria and viruses have also been found in ballast tank samples. We estimate that more than 500 different species of animals (zooplankton and benthos) and "plants" (dinoflagellates and algae) have now been found in ballast water. This number may well correspond to the number of species *in transit* in thousands of vessels around the world *on any one day.*

13. The release of species into the environment during deballasting leads to differential survival of the species involved. The greater the temperature differences between donor (source) and receiver (target) regions the greater the probability of high mortalities. Thus most organisms from tropical ports will not survive or reproduce in temperate or boreal ports, and vice-versa. Exceptions occur where tropical and subtropical species are transported to and establish reproducing populations in power plants thermal effluents, a phenomenon well-known in Europe and North America. However, many other variables in addition to temperature mediate the potential survival of newly-released organisms. Thus even when and where temperatures are similar between the ballast water and receiving waters, salinity, oxygen, light, food, and many other factors may be inhospitable or limiting. A very small number, perhaps less than three percent, of all species released by most transport mechanisms (including ballast water) actually become established in new regions. As demonstrated by the zebra mussel and many other important invaders, however, the *number of introduced species* is not related to their environmental or societal impacts. Only one successful invader is required to dramatically alter the environment.

14. Suspended materials may be taken aboard into ballast systems with water from any location. These materials may then settle in ballasted cargo holds and in ballast tanks. In cargo holds such materials may be combined with residual cargo, such as woodchip fibers

and fragments, to form a combined bottom layer (a "sludge") of chips and sediment. In ballast tanks sediments may accumulate as a mud layer. In ground-breaking Australian studies, Williams et al. (1988) reported the presence of shrimps, crabs, worms and other marine organisms in ballast tank muds. Subsequent extensive work in Australia has demonstrated that over 65 percent of cargo vessels may carry significant amounts of sediments in their ballast systems, and that these sediments may contain the abundant resting stages (cysts) of microscopic toxic marine plants (dinoflagellates, members of the phytoplankton) that can cause harmful algal blooms such as red tides.

15. Most vessels keep some type of record of ballasting operations, but there is no uniform industry standard.

16. In tankers, acknowledged ballast is highest at Los Angeles/Long Beach, with a total of over 3,000,000 metric tons (790,500,000 gallons) arriving in 1991. Remaining ports/port systems among the top five are New Orleans, Houston/Galveston, Anchorage, and New York. In bulk cargo vessels acknowledged ballast is highest at New Orleans, with a total of over 12,000,000 MT (3,160,000,000 gallons) of water arriving in 1991, followed by Norfolk with over 9,000,000 MT (2,370,000,000 gallons) of water. All other ports receive far smaller amounts, with the next four highest ports/port systems being Baltimore, Los Angeles/Long Beach, Seattle/Tacoma, and Houston/Galveston. Within general cargo vessel traffic, the top five sites are New Orleans, Houston/Galveston, Miami, Tampa, and Savannah. Thus, ports along the Atlantic, Gulf, Pacific, and Alaskan coasts all rank in the top six ports/port systems for the three types combined. On the Pacific coast, Los Angeles/Long Beach and Tacoma/Seattle are among the top tanker and bulker ports, respectively, receiving ballast water (no Pacific port is high among general cargo vessels, with Los Angeles ranking seventh in this category). On the Gulf coast, both Houston and New Orleans rank in the top five within all three vessel types, with Tampa also in the top five for general cargo carriers reported in ballast. On the Atlantic coast, different ports rank high relative to vessel type: New York for tankers, Norfolk and Baltimore for bulkers, and Miami and Savannah for general cargo. On the Alaskan coast, Anchorage ranks fourth overall for tankers.

New Orleans, with an estimated 13,484,000 MT (3,553,000,000 gallons), thus ranks as the number 1 U.S. port in terms of acknowledged ballast received from all three ship types noted above. Norfolk ranks second with an estimated 9,325,000 MT (2,457,138,000 gallons) of water received. Los Angeles/Long Beach is third with 5,878,000 MT (1,548,853,000 gallons), Houston is fourth with 3,239,000 MT (853,477,000 gallons), and Baltimore is fifth with 2,834,000 gallons (746,759,000 gallons).

17. Total acknowledged ballast arriving in U.S. waters in 1991 in bulk carriers, tankers, and general cargo from foreign ports is thus estimated to be as follows:

Acknowledged ballast water in tankers:		6,369,206 metric tons
Acknowledged ballast water in bulkers:		36,342,197 metric tons
Acknowledged ballast water in general cargo:		958,424 metric tons
	Total:	43,669,827 metric tons
		(11,507,000,000 gallons)

18. To assess the potential role of unacknowledged ballast water, we analyzed three vessel types -- bulkers, containers, and tankers -- in five ports chosen to represent the East, Gulf,

and West coasts (Baltimore and Norfolk, New Orleans, and San Francisco and Oakland). The quantities of ballast water arriving in the United States with vessels in cargo are considerable: an estimated 6,600,000 MT (1,740,000 gallons) of water enter by this route alone, or approximately 13 percent of the total volume of acknowledged and unacknowledged water combined. Almost 1.75 billion gallons of water arrive yearly by this route in the three vessel types in the five ports studied. New Orleans again ranks as the largest among these five ports in receipt of unacknowledged ballast water. Norfolk, Baltimore, and Oakland, are close behind, with San Francisco receiving a much smaller fraction. For tankers, unacknowledged ballast significantly exceeds acknowledged ballast in Baltimore. Container ships contain only unacknowledged ballast. Acknowledged ballast in bulkers always exceeds unacknowledged ballast where significant amounts are involved, but unacknowledged ballast can nonetheless be in ecologically significant quantities.

19. Based upon the above estimates of both acknowledged and unacknowledged water, it is possible to estimate the amount of ballast water arriving in the United States in vessels from foreign ports (based upon 1991 data). There are 226 U. S. ports that receive vessel traffic from foreign ports; we examined in detail 22 of these ports. The amount of water entering the remaining 205 ports is thus not known. We have conservatively estimated the impact of bulkers, tankers, and general cargo vessels arriving from foreign ports in cargo (unacknowledged ballast) and without cargo (acknowledged ballast) at these ports by assuming that one-half (100) of the ports receives at least 10 percent (that is, 239,400 MT) of the average volume of the total acknowledged and unacknowledged ballast water at each of the 21 ports (that is, 2,394,000 MT). We assume this is a conservative estimate. There are in addition more than 25 other types of ocean-going vessels in the foreign traffic that visit U.S. waters. We assumed that all of these remaining vessels release at least 10 percent of the total volume of acknowledged and unacknowledged ballast as calculated for the 21 ports for bulkers, tankers, general cargo, and container ships; this too we assume to be an underestimate.

20. These estimates indicate that approximately 79,000,000 metric tons, or almost 21,000,000,000 gallons of ballast water, arrive every year in U.S. waters in vessels from foreign ports. This is about 58,000,000 gallons per day, or over 2,400,000 gallons an hour.

21. Where does the ballast water come from? Last port of call (LPOC) data are available (by world port codes) through U.S. Census Bureau "Vessel Arrival" data.

> LPOCs for **New York, Charleston, Savannah, and Miami** are predominately either the **Northeast Atlantic** (western Europe and adjacent regions) or the **Western Central Atlantic** (Bermuda, Bahamas, Caribbean, the Gulf of Mexico, Atlantic Mexico and Central America, and northeastern South America). For New York these numbers are heavily influenced by passenger vessel traffic from Bermuda. Vessel traffic for Miami is completely dominated by cruise ships coming from the Bahamas and Haiti. LPOCs for **Boston** are the **Northwest Atlantic** (Canada) and the **Northeast Atlantic**, followed by the **Western Central Atlantic**. LPOCs for **Baltimore** and **Norfolk** are the **Northeast Atlantic** and the **Mediterranean/Black Sea region.** All but Charleston SC receive regular vessel traffic directly from the **Pacific Ocean** (Charleston receives some Pacific vessel traffic, but too rare to appear in our subsample of 1991 data). New York, Norfolk, and Charleston also receive some **Indian Ocean** traffic. All five East Coast ports receive vessels calling

from the **Mediterranean/Black Sea** regions.

All four Gulf ports, **Tampa, New Orleans, Houston**, and **Galveston**, have LPOCs from the **Western Central Atlantic** (described above under Atlantic Coast Ports). For Galveston this number is heavily dominated by vessels from the "High Seas" reflecting in large part back-and-forth traffic of the passenger vessels. For **New Orleans** the LPOCs include vessels from the **Northeast Atlantic** and from the **Mediterranean/Black Sea**. Tampa LPOCs include traffic from the **Northeast Atlantic** as well. All four Gulf ports receive traffic from the **Pacific** and **Indian Oceans**, as well as from the **Mediterranean/Black Sea**.

San Diego, Long Beach, and **Los Angeles** are predictably dominated by Pacific Rim traffic. LPOCs for San Diego are almost entirely from the **Eastern Central Pacific** (western Mexico and central America, and northwestern South America); most of this traffic consists of passenger/RoRo vessels running on regular trips between the Mexican west coast and San Diego. LPOCs for Los Angeles also show a strong western Mexico signature, with some traffic from the **Northwest Pacific** (primarily Japan, Korea, and China, and Hong Kong). **Long Beach**, adjacent to Los Angeles, shows a distinct and reversed pattern, with the **Northwest Pacific** ranking well above the **Eastern Central Pacific** (this is a reflection of the passenger traffic into Los Angeles). All three ports receive some **Atlantic** traffic; of interest is some direct traffic from the **Great Lakes** arriving in the Port of Los Angeles.

Oakland and San Francisco, Portland, and Tacoma-Seattle are similarly dominated by Pacific Rim traffic. Traffic from either the **Northwest Pacific** or the **Northeast Pacific** dominate at all ports except for Oakland, which shows a small amount of **Western Central Pacific** activity (note the total number of vessels is small, however, and thus this number is based upon only two vessels). **Northwest Pacific** traffic (primarily Japan and Korea) dominates at Portland. Canadian traffic adds to this pattern strongly in Tacoma and Seattle. All but Oakland record Atlantic traffic. Oakland may of course still *receive* Atlantic ballast water -- container ships arriving in Oakland from the Atlantic coast (and with Atlantic water) will often have an LPOC of San Diego or LA/Long Beach, "hiding" their previous Atlantic history.

Anchorage vessel traffic is dominated by traffic from Japan and Korea and other **Northwest Pacific** ports. These are, in large part, fishing vessels.

Honolulu is similarly dominated by Japanese traffic, with total **Northwest Pacific** accounting for the majority of all LPOCs. These are primarily fishing vessels. Remaining traffic of appreciable volume comes from the **Eastern Central Pacific** and from the **Southwest Pacific**. Small amounts of traffic come from the **Atlantic Ocean.**

22. The ports of Baltimore, Norfolk, New Orleans, San Francisco, and Oakland, were examined to derive a picture of the impact of *in cargo* vessels from foreign ports on LPOC diversity (on the assumption that most or all of these vessels arrive *with* ballast, or at least with "unpumpable" ballast on board, which, by mixture with newly pumped water and subsequent discharge may still lead to the release of foreign species). In addition, we

subsampled these ports to examine some domestic vessel traffic, both in and with ballast. While Baltimore and Norfolk share 18 LPOCs, each one a possible source of ballast water, Norfolk receives shipping from 15 LPOCs that Baltimore does not, while Baltimore receives shipping from 17 LPOC that Norfolk does not. The combined arrivals of Baltimore and Norfolk results in the Chesapeake Bay receiving shipping from 50 different LPOCs. The number of LPOCs for each port considered separately would be 35 LPOC (18 common + 17 distinct) for Baltimore and 33 LPOC (18 common + 15 distinct) for Norfolk. While Baltimore and Norfolk are two of the major ports in Chesapeake Bay, there are at least ten other District Ports covered by Customs in the Bay area; thus, the actual number of possible LPOCs is likely to be considerably larger than 50. The number of sources of **acknowledged** ballast (that is, vessels from foreign ports in ballast) entering Chesapeake Bay is 26 (9 in common + 17 distinct). The number of distinct **unacknowledged** LPOC's (that is, vessels from foreign ports in cargo) for the two ports considered is 24, 15 of which are unique LPOCs. This increase in LPOCs by adding foreign in cargo traffic expands the potential source regions of nonindigenous species, since many in cargo vessels are also with ballast. For San Francisco - Oakland, the foreign in cargo LPOCs account for 18 of 22 different LPOCs for that port system, as explained above. Unacknowledged ballast here may thus play a particularly significant role. As with Chesapeake Bay, the San Francisco Bay system includes other significant large ports, such as those at Sacramento (a large woodchip exporter) and Stockton, and thus the actual number of LPOCs in the San Francisco Bay system is doubtless much greater.

23. Domestic traffic for the Atlantic ports of Baltimore and Norfolk comes from the Atlantic region, while New Orleans picks up a small amount of Pacific traffic as well. The amount of Atlantic vessel traffic arriving in San Francisco Bay is difficult to determine, as LPOC data are biased by Atlantic ports "disappearing" from the record when an Atlantic vessel passes through a southern California port, as noted above for Oakland. The importance of the *source of ballast water on board*, as compared to LPOC, is thus particularly underscored by this phenomenon.

24. How good an indicator is LPOC of actual source of ballast water on board? We analyzed data to establish the relationship between LPOC and source of ballast on board. In the restricted terms of the LPOC itself, the LPOC is a poor predictor of ballast water source. For 53 percent of all vessels, there is no ballast water on board from the last port of call; this number reaches 66 percent for container ships! Exceptions would occur on some dedicated traffic lines, such as the woodchip bulkers leaving Japanese ports in ballast for Canada, the United States, Tahiti, Australia, and other countries (although with these vessels as well a certain amount of ballast water may come from offshore Japan and from the mid ocean). When LPOCs are expanded into more general Food and Agriculture Organization regions of the world's oceans, the relationship is considerably improved, with 66 percent of all vessels having at least some or all of their water from the LPOC, reaching a high of 84 percent with container ships (but a low of 33 percent for tankers).

25. Biological invasions in aquatic environments frequently have profound ecological, economic, and social consequences. Not all invasions have striking negative effects. Many invasions appear to have little obvious consequence when considered in any sense, and some invasions have had strong positive economic impacts (such as the edible Japanese littleneck clam *Venerupis philippinarum*, introduced accidentally with oysters, in the Pacific Northwest). But the number of nonindigenous species that have become predators,

competitors, and disturbers, the number of invading phytoplankters that cause toxic and harmful algal blooms, and the number of invaders that are parasites, pathogens, and other disease-causing agents of fish, shellfish, and humans, sets the stage for vector management. When and why invasions occur and the ability to recognize invaders are an integral part of this management foundation. Dramatic global ballast-mediated invasions in the 1980s have sparked a good deal of discussion as to why ballast water would or could play a greater role in the dispersal of nonindigenous species than it had previously. The Great Lakes were invaded by the zebra mussel Dreissena polymorpha and five other species of European freshwater organisms; the U.S. Atlantic coast was invaded by the Japanese crab Hemigrapsus sanguineus; U.S. Pacific coast estuaries were invaded by Chinese and Japanese copepods, amphipods, other crustaceans, and the clam Potamocorbula amurensis; Australia was invaded by Japanese dinoflagellates, and the Black Sea was invaded by American comb jellyfish. Scores of other invasions were reported as well. A global epidemic of phytoplankton blooms is now occurring (Smayda, 1990) and ballast water has played a clear role in some of these events (Baldwin, 1992; Chapman et al., 1993). These intensive patterns of invasion would lead to the prediction that additional invasions are now occurring, and will certainly occur, in the future, if the hypothesized mechanism of transport, ballast water and sediments, continues -- that is, if the faucet is not shut off or the leak not significantly reduced in some manner. However, as Carlton (1992b) has noted, "Predictions of what species will invade, and where and when invasions will occur, remain one of the more elusive aspects of biological invasion science." Why, for example, the zebra mussel successfully colonized Lake St. Clair and Lake Erie about 1986 (to be discovered two years later), remains unknown. Speculations that the zebra mussel was a candidate for introduction to North America have been made every decade since the 1920s. But by May 1988 (one month before the discovery of zebra mussels), and with the apparent failure of the mussel to appear in America, one potential conclusion would have been that the American environment was in some manner inhospitable to the zebra mussel, given the probability that it *had* been transported and released in America on more than one occasion by any of a number of transoceanic dispersal mechanisms. Six hypotheses, relative to changes in donor region, new donor regions, changes in the recipient region, invasion windows, changes in the dispersal vector and inoculation frequency, and stochastic population-inoculation events, all seek to contribute to our understanding of why invasions occur when they do.

26. A total of 103 aquatic species are identified as having been introduced to or within the United States by ballast water and/or other mechanisms. Twenty-nine species are native to America and have been transported within the United States; of these, 21 are probable ballast water species. Seventy-four species are foreign (not native to the United States). Of these, 16 are found in the Great Lakes. **Total marine foreign ballast water possible and probable introductions number some 57 species.** There is no doubt that this number represents a *significant underestimate* of the actual number of ballast mediated introductions.

27. Shipping from domestic and foreign ports can transport nonindigenous organisms not only to coastal seaports in America's brackish and marine waters, but also to inland ports in the National Waterway System (NWS). Much of the NWS includes the Gulf and Atlantic Intracoastal Waterway Systems, and thus many of the seaports discussed elsewhere in this report. Ocean-going deep-water vessels can, however, penetrate into major U.S. waterways other than the Great Lakes. Freshwater or euryhaline brackish organisms

(capable of surviving if not reproducing in freshwater as adults) can be transported up river as fouling or ballast water organisms. From these ports commercial barges, ferries, recreational boats, and a host of other vessels can transport nonindigenous species well above areas navigable by deep water vessels. Thus, barge and other vessel traffic can in theory move organisms as far north as St. Paul-Minneapolis on the Mississippi River, as well as to other deep inland ports up the Missouri, Illinois, Ohio, Cumberland, Tennessee, Tombigbee, Alabama, Arkansas, Black, Red, and Atchafalaya Rivers. Similarly, non-ocean going traffic can move organisms east of Albany up through the New York State Barge Canal, or north and east of Chesapeake Bay through the Susquehanna River.

Many inland ports are now highly modified urbanized-industrialized environments, with the native biota long since largely eliminated. Such environments are often conducive to invasions by nonindigenous species. It is clear that there are numerous portals into the American heartland. While freshwater organisms released in ballast water can gain access to the Great Lakes, the same holds true for organisms released into the freshwater rivers and ports listed above. As "back doors" to the Great Lakes and other inland water bodies, these corridors remain potential conduits for invasions.

28. The philosophy of ballast water and sediment management is similar to the basic philosophy of quarantine science in general: ballast management should seek to prevent the introduction of all organisms, ranging from bacteria and viruses to algae, higher plants, invertebrates, fish, and all other entrained life. An important corollary to this philosophy is that ***no one option or alternative*** is likely to satisfy this management philosophy. It is not appropriate to single out one alternative as "the most" likely or viable -- rather, a synthetic approach, choosing a number of alternatives simultaneously from a broad menu of possibilities, will eventually maximize the strength of ballast management. We examine here 32 control alternatives. These are as follows:

I ON OR BEFORE DEPARTURE FROM PORT-OF-BALLAST WATER ORIGIN

Water Supply: Uptake

1. Specialized Shore Facility Provides Treated Salt or Fresh Water
2. Port Provides City Fresh Water

Prevention of Organism Intake: Ballasting Micromanagement

3. Site: Do Not Ballast in "Global Hot Spots"
4. Site: Do Not Ballast Water with High Sediment Loads
5. Site: Do Not Ballast Water in Areas of Sewage Discharge or Known Disease Incidences
6. Site/Time: Do Not Ballast at Certain Sites at Certain Times of Year
7. Site/Time: Do Not Ballast at Night

Prevention of Organism Intake: Mechanical

8. Filtration

Extermination of Organisms Upon Ballasting (Ballast Treatment)

9. Mechanical Agitation
   a. Water Velocity
   b. Water Agitation Mechanisms
10. Altering Water Salinity
    a. Add Fresh Water to Salt Water
    b. Add Salt Water to Fresh Water

11. Optical: Ultraviolet Treatment
12. Acoustics (Sonic): Ultrasonics Treatment

II ON DEPARTURE AND/OR WHILE UNDERWAY (EN ROUTE)

Extermination of Organisms After Ballasting
(while at Port-of-Origin or while underway, but before arrival at destination port)
Active Disinfection (Ballast Treatment):

13. Tank Wall Coatings
14. Chemical Biocides
15. Ozonation
16. Thermal Treatment
17. Electrical Treatment (including microwaves)
18. Oxygen Deprivation
19. Filtration/Ultraviolet/Ultrasonics Underway
20. Altering Water Salinity: Partial Exchange

Passive Disinfection:

21. Increase Length of Voyage
22. Exchange (Deballast/Reballast)
23. Sediment Removal and at Sea Disposal

Deballasting Only

24. Deballast/No Reballasting

III BACK UP ZONES

25. Exchange or Deballast

IV ON ARRIVAL AT BALLAST DISCHARGE DESTINATION PORT

Water Supply: Discharge

26. Shore Facility Receives Treated and Untreated Water

Prevention of Discharge to Environment

27. Discharge to Existing Sewage Treatment Facilities
28. Discharge to Reception Vessel
29. Sediment Removal and Onshore Disposal
30. In situ Extermination of Organisms Upon Arrival (Options 8, 11, 14)

Non-Discharge

31. Non-Discharge of Ballast Water

V RETURN TO SEA: EXCHANGE WATER

32. Vessel Returns to Sea and Undertakes Exchange

29. Based upon the analyses in this Study, those alternatives that options that are most likely to be pursued for further study are:

Prevention of Organism Intake

Options 3-7	Ballasting Micromanagement

Removal and/or Extermination of Organisms

Options 7 and 19	Microfiltration
Option 11	Ultraviolet Treatment
Option 12	Ultrasonics Treatment
Option 16	Thermal Treatment (more probable for *new vessel designs*)

Options 10 and 20	Altering Water Salinity
Options 23 and 29	Sediment Management

Overall Ballast Water Operations

Option 24	Deballast/No Reballasting
Option 22	Exchange
Option 25	Back Up Zones: Deballast or Exchange
Option 28	Discharge (offload) to Reception Vessel
Option 31	Non-Discharge of Water
Option 32	Return to Sea: Deballast/No Reballasting or Exchange

30. In order to decrease the number of introductions in the future, a comprehensive system of ballast management could be considered. This system could be based as much as possible upon short-term pursuable options -- that is, those suitable for existing vessels. Most proposed "alternatives" or "options" are not immediately applicable to present day ships. The invocation of filtration, or heating, or other techniques, may be appropriate for vessels of the future (either retrofitted or new), but offer little immediate solution for present day shipping. An **INTEGRATED BALLAST MANAGEMENT (IBM)** program is proposed here as a "stop-gap" management system. This Program incorporates no new technologies; it does incorporate new programs, such as the Global Hot Spot Program, the establishment of back-up exchange zones, and the establishment of biological monitoring laboratories. IBM is a trichotomous program consisting of:

(1) **Ballast Micromanagement at the Departure Port**
(2) **Ballast Water Exchange Protocols**
(3) **Ballast Sediment Management Program**

A vessel following through departure micromanagement and exchange pathways is assigned an on-arrival status in one of four categories:

Prohibited:	(P)	A vessel prohibited from discharging its ballast water
Quarantined:	(Q)	A vessel prohibited from discharging ballast until exchange status has been determined from salinity measurements and biological sampling
Restricted:	(R)	A vessel prohibited from discharging ballast until exchange status has been determined from salinity measurements and **possible** biological sampling if required
Permitted:	(PT)	A vessel permitted to discharge its ballast water

31. Numerous complications attend the establishment of an IBM. IBM pathways are replete with exceptions, novelties, deviations, peculiarities, and irregularities. By the very nature of the thousands of possible combinations of vessels, tanks, and ballast histories, IBM -- *as with all quarantine systems* -- possesses potentially numerous holes in the dike. Integral to any quarantine system is that the system is a filter, but not an absolute barrier. ***Invasions will continue no matter what type of ballast management system is implemented, now or in the future.*** A network of tens of thousands of agricultural agents and inspectors around the world has not stopped the introduction of pest insect species. This apparent failure of the quarantine system is, however, secondary to their success -- which serves to reduce the diversity (numbers of species) and abundance (numbers of individuals) of potential colonists.

32. The relative importance of various vessel dispersal mechanisms cannot be quantified on the basis of present knowledge. No formal studies exist, for example, that have simultaneously examined the organisms in ballast systems and on the hulls of the same vessels at the same time, nor for any other mechanisms on the same vessel at the same time. Subjective approaches, based in large part upon the numbers of observed invasions combined with probable transport mechanisms for each species (that is, working backward from the discovery of an invasion to its transport mechanism), suggest that the transportation of aquatic nuisance species in ballast water and sediments is almost certainly the current leading mechanism of vessel-mediated dispersal mechanisms for shallow-water marine and brackish organisms in the world, and, for some regions (such as the Great Lakes), freshwater organisms as well. The dispersal of fouling and other organisms on ships' hulls and in ships' seachests (perhaps, as argued above, the modern-day equivalent of deep shipworm galleries of nineteenth century vessels) ranks as one of the top two mechanisms -- but this role is obfuscated by the potential assignment of a number of species to either fouling or ballast transport.

33. On the basis of the findings in this study, twelve recommendations are made. These are:

Implementation of a National Ballast Water Management Program

Implementation of a joint Canadian - U.S. North American Ballast Water Management Program

Full Scale Experimental and/or Sea Trials of Ballast Treatment and Other Options

U.S. Customs Could Expand its Data Gathering for Vessel Arrivals

Greatly Increased Attention Could be Paid to Domestic Ballast Traffic

A Ship Fouling Study Would Fill A Critical Knowledge Gap

An IMO Study Could be Undertaken on Changes in International Foreign Trade Routes and Global Shipping Patterns

A Study Could be Undertaken by the Scientific Community to Examine Invasions in the National Waterway System Study

Assessment of the Role of Military Vessels in the Transport and Release of Ballast Water

Merchant Marine and Coast Guard Academy Education Programs

Industry Education Programs

International Cooperation and Global Unified Approaches

[BLANK]

Chapter 1.

INTRODUCTION

The discovery in June and July of 1988 of the Eurasian zebra mussel Dreissena polymorpha in Lakes St. Clair and Erie of the North American Great Lakes precipitated one of the most significant periods of interest in aquatic biological invasions in U.S. history. Two freshwater invasions in the Great Lakes had preceded the discovery of the zebra mussel in the 1980s: a European crustacean, the spiny waterflea Bythotrephes cederstroemi and a European fish, the ruffe Gymnocephalus cernuus. Both of these invasions were linked to the release of freshwater ballast from cargo vessels arriving from European ports. In turn, the arrival and establishment of the zebra mussel were similarly linked to ballast water release. Within 36 months of the discovery of the zebra mussel, three more Eurasian ballast water invasions were to be reported: the tubenose goby Proterorhinus marmoratus, the round goby Neogobious melanostomus, and a second species of zebra mussel, Dreissena sp.

Thirty months after zebra mussels were found, the U. S. Congress passed Public Law 101-646 (November 29, 1990), the "Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990" (Bederman, 1991). Section 1102 of this act established a "National Ballast Water Control Program" (NBWCP) which, in turn, identified the need for "Studies on Introduction of Aquatic Nuisance Species by Vessels." An "aquatic nuisance species" is defined by the Act as,

> "a nonindigenous species that threatens the diversity or abundance of native species or the ecological stability of infested waters, or commercial, agricultural, aquacultural or recreational activities dependent on such waters."

A "nonindigenous species" is defined by the Act as,

> "any species or other viable biological material that enters an ecosystem beyond its historic range, including any such organism transferred from one country into another."

One of the studies called for under the NBWCP is the "Shipping Study", defined as follows:

> "a study to determine the need for controls on vessels entering waters of the United States, other than the Great Lakes, to minimize the risk of unintentional introduction and dispersal of aquatic nuisance species in those waters. The study shall include an examination of --
>
> (A) the degree to which shipping may be a major pathway of transmission of aquatic nuisance species in those waters;
>
> (B) possible alternatives for controlling introduction of those species through shipping; and
>
> (C) the feasibility of implementing regional versus national control measures."

In this report we use the term "nonindigenous species" (or the synonyms introduced, invasion, foreign, and exotic), rather than "aquatic nuisance species", to refer to the majority of organisms discussed here. By definition, virtually all nonindigenous species are potentially aquatic nuisance species.

The present report is the Shipping Study. This study commenced in December 1991, in

the laboratory of Dr. James T. Carlton, at the Williams College -- Mystic Seaport Maritime Studies Program in Mystic, Connecticut. It was completed in April 1993. The study assumed the working name of the "National Biological Invasions Shipping Study" or NABISS, to address the three study elements listed above. Acronyms used in this report are listed in Appendix A.

Chapter 2.

METHODS

Data Sought: Ballast Water and Port Operations

Characterization of vessel traffic and vessel ballasting operations is the first stage in achieving an understanding of the role of commercial shipping in the introduction of exotic species.

Many ports handle, to a greater or lesser extent, specific types of cargo. These cargoes in turn are often carried by specific types of vessels, each with varying loading and ballasting requirements. Depending on the type of cargo and vessel, some estimate of the ballast condition of vessels entering and leaving a given port can often be made. Various federal agencies collect some information on vessel traffic in U.S. ports. None specifically collects ballast water information on vessels carrying cargo and ballast (known as "with ballast" vessels). Some information is available on vessels travelling with no cargo (known as "in ballast") and this is useful in determining some of the more general aspects of ballast water transport.

However, with more specific port-focused and vessel-focused information available, a far more accurate understanding of ballast water transport can be had. We thus sought by direct visits to 22 selected major U.S. ports and by vessel boardings in these ports, and by a cooperative effort with USDA Animal and Plant Health Inspection Service (APHIS)inspectors, to determine the following:

(1) Ballast Water Operations: actual ballast carried versus ballast capacity, and a wide range of other data on routine ballasting, deballasting, and exchanging operations in time and space.

(2) Port Operations: vessel traffic patterns and unique port conditions relative to ballasting requirements, needs, and expectations.

We also sought, by using the above and U.S. Customs/U.S. Census data, to estimate amounts of ballast water, and where this water may be from, arriving in selected port systems in the United States. As a minimum vessel size, we selected vessels greater than 250 Net Registered Tons (NRT) and greater than 500 Gross Registered Tons (GRT); if a vessel was below both measures, it was discarded from our analyses.

Port Visits

Initial port selection was based upon the need to assess vessel traffic patterns in seven major commercial, hydrographic and biogeographic regions of the United States, as follows: (1) the Gulf of Maine, (2) the mid Atlantic, (3) the south Atlantic, (4) the eastern Gulf of Mexico, (5) the western Gulf of Mexico, (5) southern California, (5) northern California, (6) the Pacific Northwest, (7) Alaska, and (7) the Hawaiian Islands. Final port selection was based upon vessel traffic volume derived from U.S. Bureau of Census data (see below). Twenty-two ports (Appendix I) were visited, and vessels were boarded in 21 of these (Appendix B). Thus, five of the six U.S. coastlines were surveyed in this study (the Great Lakes are omitted by definition of the Shipping Study). The following ports were visited:

ATLANTIC COAST		
Gulf of Maine		
1	MA:	Boston
Mid-Atlantic Coast		
2	NY:	New York
3	NJ:	Port Elizabeth
4	MD:	Baltimore
5	VA:	Norfolk
South Atlantic Coast		
6	SC:	Charleston
7	GA:	Savannah
8	FL:	Miami
GULF COAST		
Eastern Gulf of Mexico		
9	FL:	Tampa
Western Gulf of Mexico		
10	LA:	New Orleans
11	TX:	Houston
12	TX:	Galveston
PACIFIC COAST		
Southern California		
13	CA:	San Diego
14	CA:	Los Angeles
15	CA:	Long Beach
Northern California		
16	CA:	San Francisco
17	CA:	Oakland
Pacific Northwest		
18	OR:	Portland
19	WA:	Seattle
20	WA:	Tacoma
ALASKAN COAST		
21	AK:	Anchorage
HAWAIIAN COAST		
22	HI:	Honolulu

NABISS distinguishes between a port, a port system, and a regional port system. For Chesapeake Bay, for example these would be:

Port	Norfolk
Port System	Norfolk-Newport News-Portsmouth-Hampton
Regional Port System	Chesapeake Bay (including Baltimore, Alexandria, Richmond, Newport News, Norfolk, Portsmouth, and Hampton)

Port Contacts With USCG/MSO

Initial contact with local Marine Safety Offices (MSOs) at each port was made by phone by Wendy Woods (USCG Projects Officer for NABISS). The NABISS contact person at the local MSO was determined, and the phone call was followed up by arranging for and sending (two to three weeks processing) a "Letter of Introduction" explaining NABISS and the USCG mandate under Public Law 101-646. The letter was sent from the Commanding Officer, USCG R&D Center, to the Commanding Officer of the local MSO, via the Commanding Officer of the appropriate USCG District.

The letter was followed up by Woods or Reid making telephone contact with the USCG contact person. Often the "Letter of Introduction" was re-sent by FAX at this time to assure receipt by the appropriate personnel. Dates of visits by NABISS personnel were arranged, and NABISS requirements explained. These usually consisted of the availability of one USCG member familiar with the dock areas and boarding procedures to assist in targeting (using standard USCG procedures for identifying and monitoring vessels in port) and finding vessels of interest.

Vessel boardings were planned based on the availability of vessels in the port area(s). Whenever possible, a cross section of normal vessel traffic for the port was targeted, with some preference for choosing "rare" vessel types (types of vessels that were poorly represented by boardings to that date). Vessels involved in the foreign trade were preferred over vessels involved exclusively in the domestic trade. In a number of cases where vessel traffic was light, every vessel in port was boarded, regardless of vessel type or trade route. In some cases, vessels that were on the MSO's morning report had departed by the time berth was reached, and in other cases vessels were "discovered" in port that had arrived since the morning report had been printed.

Upon boarding, ship's officers were sought in the following order of preference: 1) Captain/Master, 2) First/Chief Officer/Mate, 3) First/Chief Engineer, and 4) any officer sufficiently familiar with the vessel ballast water operations. A NABISS Vessel Questionnaire (NV) (Figure 2-1) was completed in an interview-like discussion session with the ship's officer(s). The interview took from 20 minutes to two hours, depending on the degree of difficulty in communicating due to language problems, the level of cooperation, whether the officers interviewed were on duty at the time and level of on-board activity if they were, or whether the vessel had just arrived at or was just preparing to depart from the port.

At most ports, using the NABISS Port Questionnaire (NP) (Figure 2-2) we interviewed personnel (USCG/MSO staff who had completed the Port Industry Training Program for that port, or staff in other maritime-related organizations who would have sufficient knowledge of the port) in order to gather additional general information about port operations and vessel traffic, and identify any peculiarities specific to that port relative to ballast operations (such as permanent shallows that may require vessels to deballast, low bridges that could require vessels to take on ballast, and so forth). We also obtained general information on the current economic status (growth or decline) of the port or specific shipping-related industries, as well as future prospects.

NABISS Data

On July 21, 1992 we completed our work at 22 ports and port systems on the Atlantic, Gulf, Pacific, Alaskan, and Hawaiian coasts (Appendix B). Ninety-seven vessels of 12 types were boarded (one vessel was eventually excluded as undersized, being below our parameters for vessel consideration (minimum 250 NRT and minimum 500 GRT); thus, the NABISS/NV data set

Figure 2-1

NATIONAL BIOLOGICAL INVASIONS SHIPPING STUDY

Vessel Ballast Water Questionnaire NV#:_____

Date:________ VesselName:________________ Recorder:____________
Vessel Type/Rig:________________________ Flag:____________
Officer:__________ Official No.:________ Lloyd's No.:________
NRT:__________ GRT:__________ Summer DWT:__________
Last Port-of-Call:________________ Date of Departure:________
Present Port-of-Call:________________ Date of Arrival:________
Date of Departure:________
Next Port-of Call:________________ Date of Arrival:________

For the following questions, please record units (metric tons: MT; cubic metres: m3) for all quantities.

Ballast water capacity (including designated holds):__________
Tankers: segregated ballast water capacity:__________
Total quantity of ballast water carried on arrival:__________
Greatest quantity of ballast water carried in the past month:______
Least quantity of ballast water carried in the past month:________
Quantity of ballast water normally carried when in ballast:________
Quantity of unpumpable water retained after complete discharge:_____

Record of Ballast Water Carried on Arrival:

	Source; Port Or Location	Date Taken	Quantity (MT, m3)	Salinity of Source Port
1:				
2:				
3:				
4:				

How much ballast water has been or will be taken on board from the present port (estimate if necessary):__________

Intended Points of Ballast Water Discharge (including current port since arrival) and Estimated Date of Discharge:

	Port or Location	Date of Discharge	Quantity (MT, m3)	Salinity of Discharge Port
1:				
2:				

Does this vessel keep an official record of ballasting/deballasting operations (circle Y or N);

on computer?	Y	N
in the ship's log?	Y	N
in a ballast log?	Y	N
other?	Y	N

Explain:__________

Figure 2-1 (continued)

NATIONAL BIOLOGICAL INVASIONS SHIPPING STUDY
Vessel Ballast Water Questionnaire NV#:_____

Vessel Name:____________ Vessel Rig/Type:__________ Port:_________

Can this vessel exchange all ballast water at sea? Y N
If no, how much can be exchanged?____________________________
If no, why?

Does this vessel ever exchange its ballast water? Y N
If yes, and why? (full/part/flush exchange)

How long would a complete exchange take? ________Days _______Hours
What is the capacity of the ballast pump? _________________________

Are the ships officers:
1)aware that organisms can be transported in ballast water? Y N
2)aware that the IMO is concerned with the transport of organisms in ballast water? Y N
3)aware of any country using or considering controlling ballast discharge because of organisms carried? Y N
If yes, which countries?

When fuelling, does this vessel normally:
1)discharge ballast to compensate for additional weight? Y N
2)take on ballast to maintain trim? Y N

To adjust for trim or list while docked, does this vessel normally:
1)take on or discharge ballast as needed? Y N
2)shift onboard ballast as needed? Y N

While arriving or departing a port, is there any preference to:
1)take on or discharge ballast in the port itself? Y N
2)take on or discharge ballast outside the port area? Y N

Does this vessel have a regular maintenance/cleaning program for:
1)the ballast tanks? Y N Explain.
2)anchoring gear? Y N Explain.
3)chain locker? Y N Explain.

Has sediment ever been specifically removed from any of the above locations? Y N Briefly Describe.

Would it be worthwhile to control the transport of organisms in ballast water?

Would ballast water exchange cause unreasonable problems for vessels.

Figure 2-2

NATIONAL BIOLOGICAL INVASIONS SHIPPING STUDY
Port Questionnaire NP#_____

Port:____ Date:___________
Organization:____
Representative:____

Do certain types of vessels exhibit specific ballasting practices either while in the port, or while entering or leaving? Explain.

Are there shallows where vessels regularly have to discharge ballast water to proceed, or bridges where vessels regularly take on ballast water in order to pass beneath? Explain.

What is the local perception or awareness of:
1) the question/problem of transporting and introducing organisms via ballast water?

2) the introduction of ballast water control guidelines or regulations by any country or organization?

How is the shipping traffic expected to change in the forseeable future:

1) is the port being developed to target larger or smaller ships?

2) are specific cargo handling facilities being targetted for expansion or downsizing?

3) are specific industries being developed or reduced?

consists of 96 vessels). Data gathered using NV and NP questionnaires permit us to determine the following:

* Specific sources, age, quantity, and approximate salinity of ballast on board (BOB) upon arrival (BWARR); ballast quantities to be taken at the arrival port, and specific sites and quantities of discharged water; the average amount of ballast water normally carried when in ballast (BWBT); the amount of ballast water remaining in the tanks after pumping (the amount of "unpumpable" water, BWUP).

* Typical shipboard databases that now exist for reconstruction of ballasting events.

* The ability of a vessel to exchange all of its water at sea, whether exchange had ever been undertaken and why, the length of time such exchange takes, and whether such exchange would cause unreasonable problems for vessels.

* The behavior of a vessel in routine discharge operations.

* Maintenance and cleaning programs for ballast tanks (drydocking intervals), anchoring gear, and chain lockers, and the removal of sediment from these locations.

* The ship's officers' knowledge of, and opinions on, the transport of living organisms by ballast water.

* Ballasting practices, discharge sites, and the perception of ballast as mediators of invasions by port officials.

* Port development and expectations of increased or decreased shipping traffic (port questionnaire data are supplemented with published projections).

We determined the following from these data: (1) the relationship between vessel tonnage (NRT, GRT, and summer deadweight tonnage (SDWT)) and ballast water capacity (BWCAP); (2) the relationship between BWCAP and BWBT (specifically, the ballast water normally carried while a vessel is "in ballast"); (3) an estimate of the amount of ballast water carried into U.S. ports by vessels travelling "in ballast," and (4) estimated volumes of unacknowledged ballast water. In turn, NABISS and additional port and shipping information questionnaires (through APHIS cooperation, see below) were used to determine (5) the relationship between BWCAP, or other measures of vessel size, and the average amounts of BWARR (ballast water quantities carried on arrival by various ship types under normal operating conditions). This permitted us to estimate the amounts of ballast water brought into U.S. ports by vessels travelling "with" (and "in") ballast.

Additional Port and Shipping Information

Further port and shipping data were gathered by contacting the following groups or offices:

Maritime/Shipping Associations/Exchanges

Where present, these offices often have the most information, the most comprehensive information, and the easiest available information (e.g. New York). Individual vessel

listings are compiled in a few ports (New York/New Jersey), while monthly and/or annual reports are usually published. Computer discs are sometimes available in addition to hardcopy reports. Where these agencies are not present (e.g. Savannah, Tampa) or normally do not record vessel traffic information (e.g. Boston, Charleston), other offices may take over many of the activities otherwise associated with them (e.g. Charleston Branch Pilots Association, Tampa Port Authority, Boston Massport).

Port Authorities

These offices have varying amounts of useful and/or available information. While in most harbors they primarily collect and maintain records of vessel traffic in and out of those berths that they operate, in some cases they have extended their information-gathering and record-keeping to include most or virtually all of the commercial vessel activity in the area (e.g. South Carolina State Port Authority, Tampa Port Authority, Boston Massport). Vessel traffic information is sometimes available on computer disc.

Pilot Associations

These offices usually collect only whatever information is required in billing the vessels or their operators for services rendered. This information is normally available from other sources.

Harbor Masters Offices

In general, these offices are more involved with the maintenance of city-owned shoreside facilities or dredging operations. They rarely deal with harbor operations on a day-to-day basis and generally do not collect information on vessels or vessel traffic.

Vessel Traffic and Ballast Data

For our purposes, commercial vessels can be divided into two overall groups: those ***in ballast***, travelling with no cargo and therefore (more or less) fully ballasted, and those ***with ballast***, travelling with a partial or full load of cargo and some amount of ballast below their full capacity.

In ballast vessels can be identified through the information published by the Bureau of Census in the Monthly Vessel Entrances (TM-385) and Clearances (TM-785) listings. We refer to this published information as ***acknowledged ballast***. The amount of ballast water carried by vessels in this group can be approximated from the ballast water capacity sometimes listed in references such as Lloyd's Register (estimated by vessel type, from regressions that we developed, if the actual capacity is unknown), and modified by a factor of actual amounts of ballast carried when in ballast or in cargo determined from information collected during vessel boardings.

All other vessels fall into the second category, those with ballast, and include those vessels that would consider themselves to be travelling with no ballast water on board (NOBOB). We refer to this water as ***unacknowledged ballast***. Thus if ships are not fully loaded or are carrying a light load a large amount of ballast water may be carried but not acknowledged since the vessel is said to be in cargo. Our experience indicates that these vessels may carry 50-500 metric tons (that is, up to 132,000 gallons) of "unpumpable" ballast water. The volumes of ballast carried by various vessel types were estimated for the different ports based on the information collected during vessel boardings. This ballast may be discharged by vessels subsequently ballasting and deballasting water, thereby mixing and discharging ballast, as cargo is handled in U.S. ports.

We used the 1991 U. S. Census TM-385 data for the port systems that we visited, combined with our analyses and calculations of NV and APHIS (see below) data to determine ballast volumes (acknowledged and unacknowledged) to calculate:

(1) How many vessels arrived at each port
(2) How many of these vessels were in ballast, and from a foreign port
(3) How much ballast these vessels carried
(4) The "last port of call" (LPOC) of the vessel

Methods for Calculating Acknowledged Ballast

In order to estimate the quantities of acknowledged ballast entering the 22 selected ports, a subsample of the ships reported in ballast was taken from the Census data (Vessel Entrances TM 385 1991) in the following manner. For each port, five in ballast vessels per month were picked at random and vessel name, flag, and NRT recorded. This information was used as a cross reference in order to identify ship type from Lloyd's Register and Record of the American Bureau of Shipping. If a month had less than five in ballast ships for that port, then a ship from another month was randomly selected and added. If the ship type could not be ascertained then another vessel was randomly selected. These replacements never represented more than 13 percent of the total sample (n=60) for any particular port, and on average represented 3 percent. If a port had less than 60 ships in ballast for the year then all ships in ballast were included in the sample.

Regressions relating Gross Registered Tons (GRT) or Dead Weight Tonnage (DWT) to the ballast capacity of a ship were developed for Bulk Carriers, Tankers, and General Cargo ships. Included in Bulk Carriers are Wood Chip Carriers, Oil/Bulk/Ore vessels (OBO), Oil/Ore Carriers (O/O), and Cement Carriers. Included in Tankers are Liquid Gas Carriers (Liquid Petroleum Gas (LPG), Liquid Natural Gas (LNG)), and Chemical Tankers. These three ship types represented 60 percent of the ships that were in ballast in the subsample. Passenger ships, while they represented 17 percent of all ships in ballast in the sub-sample, were not included in calculations of incoming acknowledged ballast. Since these ships are not contracted to carry cargo they are by default considered by Customs to be in ballast, regardless of their ballast condition (some of the TM 385 data is derived from Customs Form 1400 data). The quantities of ballast that these ships carry and discharge is normally small. Ballast arriving was not calculated for the 21 other ship types which make up the remaining 23 percent of the ships in ballast. Ballast arriving was also not calculated for vessels of 250 NRT/500 GRT or less. Not all vessel types appear at all the ports by this subsampling method; indeed, for San Diego, no in ballast tankers, bulkers, or general cargo ships appeared.

The data for the regressions came from the APHIS Survey questionnaire (see below), providing a large sample size (n = 1034 vessels). Ballast capacity data were square root transformed since plots of the standardized residuals displayed evidence of some unevenness in the variance of the data. The independent variable (tonnage) was also square root transformed for the tanker regression in order to improve the regression. Once the independent variable was determined, the mean independent values (where possible) were determined for each of the three ship types for each of the 22 ports. In some ports, for some ship types, the sample sizes are low, so that values obtained may or may not be representative of the mean ship size, for that ship type, at that port. However, uncertainty due to a small sample size is more than offset by the small quantities of ballast contributed using these data, since the low sample size is again reflected in the low proportions of that ship type entering the port in ballast.

These values were then placed into the regressions to estimate a mean ballast capacity for each of the ship types entering each of the ports. The proportion of in ballast Bulk Carriers, Tankers, and General Cargo vessels entering each port was determined from the sub-sample. This number was multiplied by the number of in ballast ships arriving at each of the ports in order to estimate the number of in ballast arrivals of that ship type for that port. The estimated number of in ballast arrivals was then multiplied by the mean ballast capacities determined from the regressions to obtain total ballast capacity that could arrive. Since ships do not necessarily carry full capacity when travelling in ballast, this number was then multiplied by the average percentage of capacity (value derived from NV data) that each ship type normally carried when travelling in ballast.

Methods for Calculating Unacknowledged Ballast

A sub-sample of vessels entering five of the 22 visited ports was taken in order to estimate the unacknowledged ballast water being discharged into U.S. waters. The ports chosen for this further analysis of the sources and amounts of unacknowledged ballast water were Baltimore MD, Norfolk VA, Oakland CA, San Francisco CA, and New Orleans LA. The ports of Baltimore and Norfolk were chosen to represent the Chesapeake Bay system and hence the Atlantic coast, Oakland and San Francisco were chosen to represent the San Francisco Bay system and hence the Pacific coast, and New Orleans was chosen as representative of the Gulf Coast.

A sub-sample of the first 48 ships from every other month (beginning with January) was taken for each of these ports (n=288 for each port) from Vessel Entrances TM385 Census data (1991), and included vessel name, flag, NRT, LPOC and ballast/cargo condition. Vessel name, flag and NRT information was used to identify ship type in Lloyd's Register. Ballast/Cargo condition information (Census data) indicated if the ship arrival was foreign or domestic and in ballast or in cargo. If one of the first 48 ships could not be found in Lloyd's, it was replaced by the next ship in the census listing. This process continued until the sub-sample was complete. The only exception made was for ships with a net registered tonnage of less than 250. These ships were not included in the survey since the small size of these vessels quantities of ballast would be minimal. Also, most ships in this size range and smaller are not registered with Lloyd's Register or the Record of the American Bureau of Shipping and so information as to ship type is not readily available.

Unacknowledged ballast was determined for three ship types: Bulk Carriers, Tankers, and Container ships. Included in Bulk Carriers were Oil/Bulk/Ore Carriers, Oil/Ore Carriers, Wood Chip Carriers, and Cement Carriers. Included in Tankers were Liquid Gas Carriers (LPG & LNG) and Chemical Carriers. These three ships type were chosen since they represented a majority of all vessel traffic. For each of the ship types in each of the ports the proportion of ships that were from foreign ports and in cargo was determined. This percentage was then multiplied by the total number of arrivals in order to estimate the number of vessels arriving from foreign ports in cargo. This was then multiplied by the average percentage that BWARR represented of BWCAP when in cargo in order to estimate the average unacknowledged ballast entering a port. The average ballast tonnages used in these calculations were derived from NABISS/NV boarding data.

Determining Ballast Water Source

As noted above, we used Census Bureau data to determine the LPOC for vessels coming

into the 22 selected ports. LPOC data were then converted to the standardized ocean regions of the world as used by the United Nations' Food and Agriculture Organization (FAO) (Figure 2-3). We then used APHIS data (below) to determine the relationship between actual LPOCs, LPOCs as converted to FAO regions, and the actual source of the ballast on board.

THE APHIS SURVEY

Background

During the course of our port visits and based upon discussions with personnel in the shipping industry, it became apparent that the USDA's Animal and Plant Health Inspection Service (APHIS) was the only federal agency that boarded virtually all foreign trade commercial vessels entering U.S. ports. Discussions with APHIS field personnel suggested that it would be possible for APHIS inspectors to carry aboard with them a simplified version of our NV questionnaire during a pre-arranged "ballast month" so that ports around the nation would be visited more or less simultaneously in the same 30 day period. The purpose of the survey was to collect basic ballast water data for all vessels (with and without cargo) entering the selected port systems from foreign ports. APHIS inspectors board virtually all foreign-trade commercial vessels, but only vessels arriving at their first U.S. port are thoroughly inspected. Vessels travelling coastwise to subsequent U.S. ports are often only boarded to check on-board garbage and a few other basic protocols. August 1992 was targeted as "Ballast Month." An example of the APHIS questionnaire and instruction sheet is shown in Figure 2-4.

Survey Organization

USCG/MSO offices usually supplied phone numbers and contact names for the local APHIS office. APHIS offices were contacted as part of our port visits wherever possible (beginning with Baltimore; March 25, 1992), or by phone with follow-up contact by mail outlining our request for aid in vessel surveys, and supplying background information (copies of USCG letters of introduction for the local MSO and a list of APHIS offices and personnel already contacted and giving us a positive response). Norfolk, Charleston and Port Elizabeth APHIS offices were contacted solely by phone. Initial prototypes of the questionnaire were shown to several APHIS offices during our port visits for their comments and suggestions.

By early July, all APHIS offices involved in the survey had been contacted for the number of questionnaires and instruction forms they would require. From 20-400 questionnaires and from 5-40 instruction sheets were sent to the 18 APHIS offices responsible for the 22 ports studied (at least one instruction sheet for each 10 questionnaires). Recent copies of articles on zebra mussels, cholera incidences in Mobile Bay, Alabama, and general information on introduced species were also included. Most of the packages were prepared on July 10 and were sent out in the mail on July 11. The packages for Portland, Seattle and Anchorage were hand-delivered during our port visits in July.

The survey was conducted through the month of August, with a few questionnaires received from late July and early September. After the survey (or in some cases in installments through August), the completed questionnaires were returned to the NABISS offices.

Handling of the Forms and Information

The 1285 questionnaires received were placed in binders by port. A spreadsheet was set up using QuattroPro, with a column devoted to each answer space on the questionnaire, and with an additional column for comments (these were usually additional comments by the inspectors or remarks on unexpected responses to the questionnaire noted during checking or entering of the

Figure 2-3

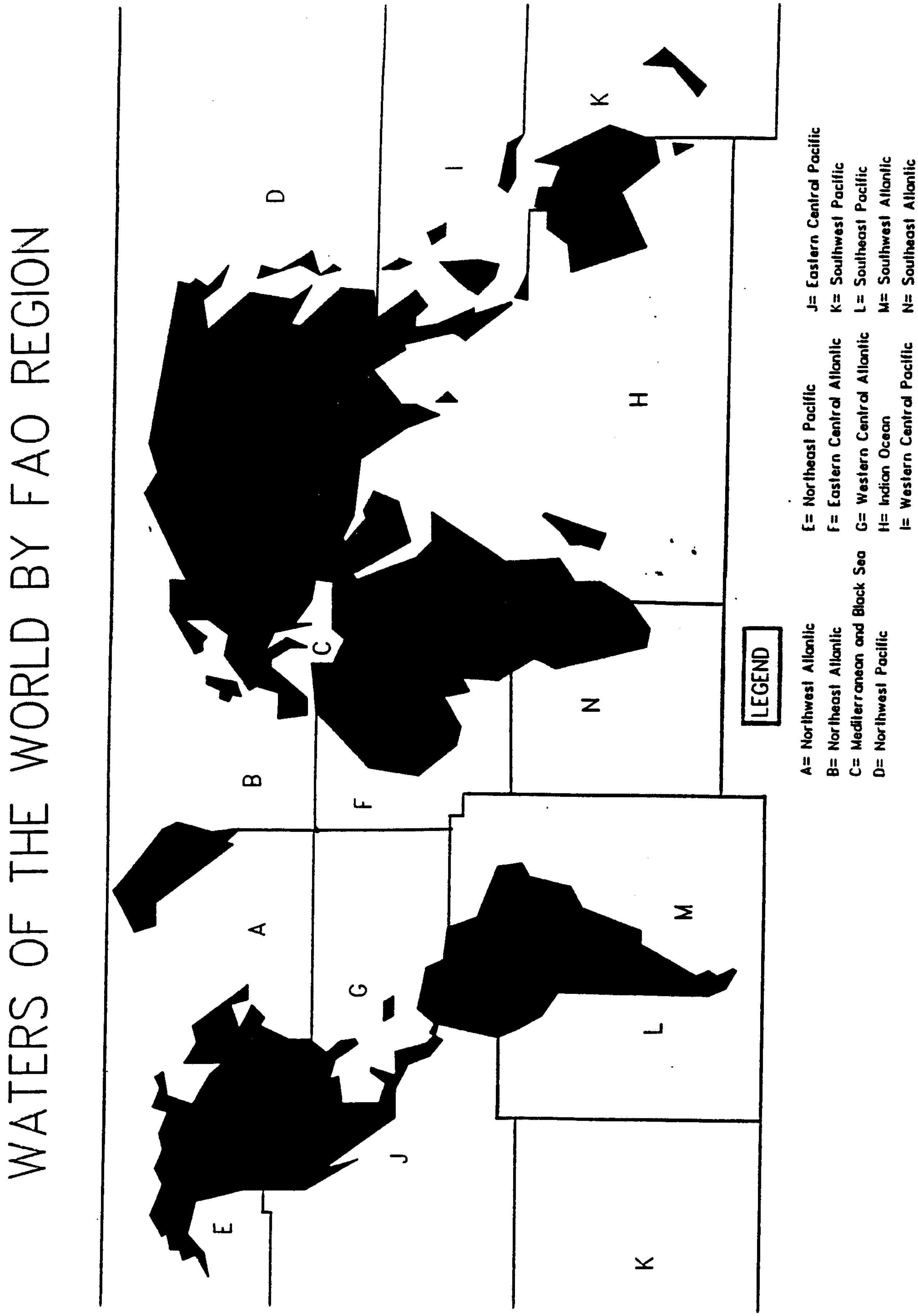

WATERS OF THE WORLD BY FAO REGION
A
B
C
D
E
F
G
H
I
J
K
K
L
M
N
LEGEND
A= Northwest Atlantic
B= Northeast Atlantic
C= Mediterranean and Black Sea
D= Northwest Pacific
E= Northeast Pacific
F= Eastern Central Atlantic
G= Western Central Atlantic
H= Indian Ocean
I= Western Central Pacific
J= Eastern Central Pacific
K= Southwest Pacific
L= Southeast Pacific
M= Southwest Atlantic
N= Southeast Atlantic

Figure 2-4

NATIONAL BIOLOGICAL INVASIONS SHIPPING STUDY

United States Coast Guard Research and Development Center
Non-Indigenous Species Research Project

APHIS Vessel Ballast Water Questionnaire

Port of ____________________

Date:________ Vessel Name:__________________ Flag:____________
Official No.:__________ GRT:__________ Summer DWT:____________

Vessel Type (check from the following; more than one check may be appropriate as in a combined General Cargo/Container Carrier):

__: Container Carrier __: General Cargo Carrier
__: Bulk Carrier __: Oil/Bulk?ore Carrier (OBO)
__: Tanker __: Chemical Tanker
__: Roll On/Roll Off (RoRo) __: Refrigerated Carrier (Reefer)
__: Cruise Ship __: LASH (Lighter Aboard Ship)
__: Other (Please specify):______________________________

Last Port-of-Call (port and country):____________________
Date of Departure from Last Port-of-Call:________________

Next Port-of-Call (port and country):____________________
Date of Arrival at Next Port-of-Call:____________________

For the following questions, please record units (metric tons: MT; long ton: LT; cubic metres: m3; or other) for all quantities.

Ballast water capacity of the vessel:____________________
(Include holds designed to carry ballast)
Total quantity of ballast water carried on arrival:____________
(If officer reports no ballast water on board, write 0 or nil)

Sources (may be several) of ballast water carried on arrival:

	Source; Port Or Location	Quantity (MT, m3)
Source 1:	______________________________	____________
Source 2:	______________________________	____________
Source 3:	______________________________	____________
Source 4:	______________________________	____________

What will be the total quantity of ballast water that has been or will be discharged in this port before the vessel departs (estimate if necessary):____________________

What will be the total quantity of ballast water that has been or will be taken on board from this port before the vessel departs (estimate if necessary):____________________

Completed by:______________________________

Instructions for Completion of the APHIS Vessel Ballast Water Questionnaire

These questionnaires should be completed with the assistance of the captain, first (or chief) officer (or mate), or chief engineer; in that order of preference. The captain may recommend another officer as being more familiar with ballast operations, although any of these officers usually have, or at least have access to the information required. If none of these officers is available (occurs rarely), any officer sufficiently familiar with the ballast operations would be acceptable. **Please emphasize to the officers that this is a survey to gather information, it is not an inspection or examination.** It is hoped that the questionnaire can usually be completed in about five minutes.

Since individual APHIS offices may cover several ports, please record the specific port where the vessel has docked or will dock.

The first part of the vessel questionnaire can be completed from the list of "Ship's Particulars"; ask the available officer to see a copy of this form. Explanation of terms:

Flag: Country of registry
Official No.: Official number in country of registry
GRT: Gross registered tonnage
Summer DWT: Summer deadweight tonnage

Whenever a quantity or volume is required, confirm and record units used; long tons (LT), metric tons (MT), cubic metres (m3) or other. Wherever information is an estimate rather than an exact amount, write "approx" (for approximately) in front of the number.

Record **both** port and country for Last and Next Port-of-Call, and record dates numerically as month/day/year (00/00/92).

The ballast water capacity may be on the "Ship's Particulars" list, but this and the volume of ballast water carried on arrival at the port should be available from the ship's officer. Source(s) and volume(s) of ballast water may require the officer to check the ship's records, and only part of this information may be available. Where the ship's records and/or the officer's memory cannot provide this information, enter "unknown" in the appropriate space.

The last two questions on the quantities of ballast water taken on or discharged (up until the ship's departure from the port) can only be answered by the ship's officers. Often, this will be an estimate of the expected quantity of ballast to be discharged or taken on. If, for example, an officer reports that 500 metric tons of ballast will be discharged, and then another 500 metric tons will be taken on (this does happen occassionally), please record both quantities on the form even though there would be no net change in ballast water carried.

Additional notes may be written in the margin; please print clearly. Again, thank you for your assistance.

information).

Every form was inspected for usefulness based on information recorded, readability and contradictory data, to determine whether all of or what parts of the questionnaire were usable. "Discards" or "special discards" were noted and separated (see below). The information from all accepted forms was recorded in the spreadsheet. Where possible, information was added or verified using Lloyd's Register, and in a few cases other questionnaires recording the same vessel could be used for verification of some information. A total of 1034 questionnaires were usable (80 percent).

Reasons for Discarding APHIS Questionnaires

APHIS questionnaires were discarded for the following reasons:

1) vessel type was not a commercial cargo vessel of the type under consideration in the survey (e.g., navy vessels, fishing boats, tugs, tall ships, navy or research vessels; these were retained as "special discards" (39 questionnaires, or 3 percent).
2) LPOC was another U.S. port, or the anchorage or lightering area of the current port (most of the discards not covered by (1); 137 questionnaires, or 11 percent).
3) the ballast water portion of the form was blank (i.e. only information describing the vessels was recorded; name, GRT, etc.).
4) contradictions in the answers were sufficient to make the form unusable, eg. the ballast water capacity was greater than the summer deadweight tonnage of the vessel (usually 25-50 percent of DWT), or the amount of ballast water carried on arrival in the port was greater then the ballast water capacity. In some cases the contradictions were reconciled by Lloyd's, but more often only part of the contradictory information was unusable (based on other supporting or non-supporting information) rather than discarding the entire form (see "Interpretations" below).

Categories 3 and 4 represent 39 questionnaires, or 3 percent, of the total received.

Interpretations

1) when information was contradictory, there was often additional information which allowed us to interpret the particular situation based upon our previous familiarity with ballasting operations. This permitted us to use some of the information provided rather than discard the form; only when the information was very limited, and we could not determine if any of the information were reliable, would the questionnaire be discarded.

2) when the quantity of ballast carried or the quantity listed under sources was greater than the quantity of ballast water carried on arrival, the latter was recorded to keep the values conservative.

3) long tons were converted to metric tons by: MT = 1.016 LT; cubic meters were converted to metric tons of seawater by: MT = $1.025m^3$.

Lloyd's Register

In many cases, some of the vessel information at the top of the questionnaire was left blank. Given the vessel name and one or two other pieces of identifying information (flag, official number, GRT, SDWT, vessel type), the vessel could usually be located in Lloyd's and the missing information added. Lloyd's records SDWT in metric tons; this information was used as a check when units were not recorded and where units used by the country of registry were unknown or variable (eg. Liberian registered vessels recorded their SDWT in either metric tons or long tons). Occasionally ballast water capacity was recorded in Lloyd's, and this was used when capacity was not recorded on the questionnaire, or where the capacity recorded was obviously in error; eg a 10,000 SDWT vessel with a reported ballast water capacity of 100MT, or 12,000 MT.

It should be noted that not all registry countries determine vessel tonnages in the same manner. For example, a theoretical vessel registered in Liberia at 10,000 gross register tons may be measured differently if registered in another country, and any information we retrieved from Lloyd's would be measured according to Lloyd's procedures. Additionally, vessels may often undergo structural modifications throughout their useful life, resulting in increases or decreases to their tonnage figures, which would not be recorded in Lloyd's until vessel updates were issued or until the following year (at the earliest) and may or may not be reflected in the Ship's Particulars. All of these factors need to be recognized when determining relationships between vessel size (based on various tonnages) and characteristics such as ballast water capacity.

While problems of uniform data capture were naturally encountered in this first trial run of an instantaneous national ballast water survey, the immediate and initial success of this project is notable.

Vessel-Mediated Dispersal Mechanisms and Biological Invasions

The range of dispersal mechanisms associated with shipping, and the resulting invasions in U.S. waters (particularly for ballast water associated species), were determined from NABISS vessel interviews and from literature, records, and personal observations, gathered and obtained by J. Carlton from 1962 to 1992.

Chapter 3.

SHIPPING AS A MAJOR PATHWAY OF TRANSMISSION OF NONINDIGENOUS SPECIES: MECHANISMS OF DISPERSAL OTHER THAN BALLAST WATER AND SEDIMENTS

Introduction

Vessels have been long recognized as dispersal agents of living organisms. The earliest ships carried maritime semiterrestrial organisms inside and marine fouling organisms on the outside of the vessel, and boring organisms in between (Carlton, 1992a). Ships have been the greatest agents for the movement of plants and animals between continents for centuries. As a result, the modern-day distributions of thousands of species of plants, fungi, molds, nematodes, earthworms, insects, spiders, millipedes, mites, ticks, snails, slugs, mammals, and many other organisms can be explained in terms of human colonization by ships and historic commercial vessel traffic across the globe.

The role of vessels as dispersal agents of freshwater, brackish water, and saltwater organisms is, however, not as well known. Scientific investigations of land-dwelling plants and animals are of sufficient antiquity (extending back to 16th and earlier centuries) that the role of human transport of terrestrial organisms can be more easily recognized. Scientific records of the aboriginal distributions of aquatic species are often 200 to 300 years younger, and thus provide a poorer foundation for examining the role of human-mediated dispersal -- that is, the first descriptions of the animal and plant life of most coastal waters of the world appear two or three centuries after ships had acted as the main vehicles of colonization and commerce to those waters (see also comment by Pollard and Hutchings, 1990, p. 243). Indeed, reliable distributional data, if such exist, for most aquatic organisms date only from the 20th century. In many cases, such data do not exist at all. As a result, many freshwater and marine biogeographers and systematists have classically viewed, and continue to view, many distributions of plants and animals as "natural" if clear evidence of human-altered distribution patterns is lacking.

There have been and are hundreds of types of watercraft operating upon the world's canals, rivers, lakes, and oceans. There is no universal vessel classification system. Vessels ranging from rafts, dugouts, skiffs, and canoes to bulk carriers, oil tankers, and aircraft carriers are capable of transporting organisms from one body of water to another and from one continent to another. Table 3-1 summarizes the major types of vessels now engaged in operation on the world's oceans; we use these categories and names here. There are three major divisions:

I **Passenger vessels**, including passenger liners, ferries, and excursion boats

II **Cargo vessels**, including bulk carriers, container ships, and tankers

III **Specialized vessels**, including barges, fishing vessels, and semisubmersible exploratory drilling platforms (referred to as SEDPs by Carlton (1987, p. 455)).

The Ship as a "Biological Island"

The concept of the vessel as a "biological island" has never been thoroughly explored. We

TABLE 3-1
VESSEL TYPES AND TONNAGE MEASUREMENTS

AKA = also known as

I. PASSENGER VESSELS

- Passenger vessel [ships with a capacity for 13 or more passengers]
  (AKA: passenger liner, cruise liner, cruise ship)
- Ferry
  types include:
  - Passenger/train/vehicle: all combinations
    [Note: most train/vehicle ferries are Ro-Ro]
- Excursion boats
  types include:
  - Private: yacht
  - Public: many types
- Combination
  types include:
  - passenger/cargo
  - passenger/container

II. CARGO VESSELS (AKA: Freighters)

- General cargo
  see also multipurpose cargo vessels and bulk carriers (under 'Combination', below) (containers may be carried as deck cargo)
- RoRo (acronym for "Roll on - Roll off")
- Reefer
  (AKA: refrigerated vessel, refrigerated cargo ship, fruit ship)
- Gas carrier
  several different types; see also liquid gas carrier
- Chemical carrier
  see also chemical tanker
- Cement carrier
- Coal carrier
  (AKA: collier); see also 'Combination', below
- Ore carrier
  see also 'Combination', below
- Pallet carrier
- Car (vehicle) carrier
  see RoRo; also multipurpose cargo vessel
- Timber carrier
  (AKA: log ship, lumber ship)
- Woodchip carrier
- Barge carrier [vessel designed to carry barges and/or containers]
  LASH (Lighter Aboard SHip)
- Livestock carrier
  most are conversions from other ship types
- Fish carrier
  see fishing vessels
- Fuel oil carrier
  see tanker

TABLE 3-1 (continued)
VESSEL TYPES AND TONNAGE MEASUREMENTS

- Liquid gas carrier
  (AKA: independent tank carrier, pressure tank carrier)
  types include:
  LPG - Liquified Petroleum Gas
  LNG - Liquified Natural Gas (for example, nitrogen, propane)
- Bulk carrier (bulker) [Vessels designed to carry dry bulk cargo]
  see also: cargo vessels (above) and combination carriers (below)
  types include:
  - general (purpose) bulk
  - special bulk
  - dry bulk
    [cargo which is loose, granular, free-flowing or solid but is not packaged; examples are grain, coal, ore. Such cargoes are handled by specialized mechanical equipment usually at dedicated dry bulk terminals]
  - break bulk
    [mixed items of general cargo, packaged and moved as single parcels or assembled together on pallets which are hoisted on and off a vessel by wire/rope cargo slings with the ship's or wharf's cranes]
  - self unloader (these are in Great Lakes service)
- Container ship (AKA: freighter) [full or partial container ships]
  types include:
  - general container ship
  - short-sea container ship (AKA: container feeder ship)
- Tanker
  types include:
  see also: Combination carrier (below)
  - tanker: oil, oil/crude, oil/product, fuel oil
  - coastal tanker (AKA: short-sea tanker)
  - deep-sea (oil) tanker
    ULCC - Ultra Large Crude Carrier
    VLCC - Very Large Crude Carrier
  - chemical tanker (different types)
  - oil/chemical tanker
  - product tanker (molasses, wine, fruit juice, etc.)
- Combination (AKA: partial containerships, in part)
  types include: combination cargo:
  - multipurpose cargo vessel
    (some may be RoRo; may carry containers, bulk cargo, breakbulk, general cargo, packaged timber, cars)
  - combination carrier

O/O	- Ore/Oil	O/B/O	- Ore/Bulk/Oil
O/B	- Ore/Bulk	O/C	- Ore/Coal

    Container/Bulk (AKA: Conbulker)
  - general cargo/container ship
  - general cargo/container/RoRo
  - RoRo/cargo ship
  - RoRo/container ship
  types include: combination cargo - non cargo:
  - crew/supply vessel, tug/supply vessel, mooring/towing vessel
  - tug/container carrier
  - passenger/vehicle carrier: see ferry

TABLE 3-1 (continued)
VESSEL TYPES AND TONNAGE MEASUREMENTS

III. SPECIALIZED VESSELS

- Barge

  <u>types include:</u>
  - manned, unmanned, self propelled
  - barge carrier/cargo:
    many types (acid, garbage, dump, cement (including storage))
  - dredge (see dredger below): many types of suction, hopper, unloaders
  - derrick, crane, accommodation, deck house
  - pipe laying, pipe burying
  - diving
  - grain elevator, freezer
  - pile driver/construction,
  - drilling (platform, rigs, barges): see also 'Other', below
    (propelled/nonpropelled, jackup, self-elevating, other types)

- Fishing Vessels

  <u>types include</u>:
  - sport fishing
  - trawlers, seiners, longliners, traps (e.g. lobster)
  - fish cannery, fish packer, fish processing, fish carrier
  - stern-trawling fish factory ship

- Other

  <u>types include:</u>
  - research ship; survey vessel (research)
  - hospital ship
  - naval vessels (many types) and naval support (including many types listed
    elsewhere in this table)
  - landing craft
  - patrol boat
  - buoy tender
  - ice breaker
  - training ship, tall ship

  - tug, pushboat, tow boat
  - cable layer (also called: cable ship)
  - high speed ships (planing, jet-propelled)
  - hydrofoil
  - support ship (submersible)
    (often converted stern trawlers; multi-purpose, may be used in diving
    support, standby safety, supply, etc.)
  - semi-submersible heavy-lift vessel
    (also called: semi-submersible deck cargo ship)
  - heavy-lift cargo ship or heavy load deck cargo ship
    (note: many general cargo vessels are fitted with heavy-lift derricks)
  - oil rig supply vessel (ORSV) (also called: pipe carriers)
    (note: many ORSV's are also tugs (tug/supply vessels))
  - dredger (see barge above also)
    (includes: suction dredger, hopper suction dredger, bucket dredgers,
    cutter suction, are smaller similar harbor craft)

TABLE 3-1 (continued)
VESSEL TYPES AND TONNAGE MEASUREMENTS

- drill rigs (see barge above)
  (propelled/nonpropelled; fixed, semi-submersible, tension leg platform (TLP), jackups, conical drilling unit, column stabilized , mobile Arctic caisson)
- drill ships
  (semi-submersible exploratory drilling platform - column stabilized drilling unit; some may also be converted bulk carriers, tankers)
- supply/tender
- launch (also called: utility boat)
- deck cargo pontoon

Sources of Information for Vessel Types:

Record of American Bureau of Shipping (1991)
Lloyd's Register of Ships (1990-91)
Jane's Merchant Ships, Third Edition (1987-88)
Ships on Register in Canada: List of Ships (volumes I, II), Canadian Department of Transportation, Catalog No. T34/-1 (1990)
Bulk Carriers of the World: Oceangoing Merchant Type Ships of 1000 Gross Tons and Over (excludes vessels on the Great Lakes), U. S. Dept. of Transportation, Maritime Administration (MARAD), Office of Trade Studies and Statistics (1981)
MARAD (1991)
Canadian Coast Guard, Ship Safety Office (Montreal) (1992)
USCG Marine Engineering Group, Avery Point (1992)
Society of Naval Architects and Marine Engineers (SNAME)

MEASUREMENTS OF VESSEL VOLUME AND WEIGHT

Merchant vessel tonnage is described in two ways, by volume and by weight, as follows (DeKerchove, 1961; Janes Merchant Ships, 1988; MARAD, 1991):

Gross tonnage or Gross Registered Tonnage (GRT) is a measure of volume, the cubic capacity of the vessel expressed in gross tons (100 cubic feet (2.83 cubic meters) of permanently enclosed space equals one gross ton).

Net Registered Tonnage (NRT) (net tonnage) is a measure of volume, specifically referring to the "earning capacity" of the vessel. NRT = GRT minus officers, crew and passenger quarters, machinery spaces, and fuel spaces. Dock, canal, port, and harbor dues and fees are normally paid based upon NRT.

Deadweight Tonnage (DWT) is a measure of the carrying, or lifting, capacity of the vessel, and includes the weight of the cargo, fuel, potable water, provisions, furnishings, gear, service tanks and piping, passengers and crew and their effects, and the **ballast** and **bilge** water. In maritime terms, it is the weight required to bring the vessel from "light" to "loaded displacement" or "full displacement" (thus, DWT is the difference between the light vessel weight and the displacement loaded: a "deadweight scale" is used to plot the DW capacities corresponding to the various drafts of water between light and loaded displacement). DWT is measured in long tons (2,240 pounds) in the United States and elsewhere in metric tons (tonnes, 2,205 pounds).

present here a synthesis (Table 3-2) of this concept. Organisms can occur in one of three regions on a vessel: on the outside, on the inside, and aboard the vessel.

Organisms on the Outside of the Vessel

Fouling organisms ("biofouling") occur on the hull, rudder, and propeller of modern vessels. Anchors may become fouled as well, as would any underwater structures (such as pontoons) of any vessel (for example, semisubmersible exploratory drilling platforms). Carlton (1985, 1987, 1989) noted some of the classic literature on ship fouling organisms. These works include Hentschel (1923, 1924), Visscher (1928), Edmondson (1944), WHOI (1952), Allen (1953), Skerman (1960), and Clapp and Kenk (1963). More recent works discussing vessel fouling include Zibrowius (1979), Huang et al. (1979), Evans (1981), Dalley and Crisp (1981), Callow (1986), and Bagaveeva (1988).

Why, when, and how fast fouling proceeds depends upon the resistance or susceptibility of the exposed surfaces to larval or propagule settlement and recruitment and the length of time of exposure. Henschel and Cook (1990) have summarized the variety of processes that occur as soon as a non-reactive solid is immersed in the sea and inorganic, organic, and biotic matter accumulate on its surface. An initial post-immersion event is the adsorption of dissolved molecules, a phenomenon that may influence ensuing colonization. Bacteria are typically the first colonizers; large populations develop and produce mucilage, an acid mucopolysaccharide of fibrous reticular nature which helps to bind the bacterial colonies to the surface and may form a thick layer. Other initial colonizers can include diatoms, fungi, and cyanophyte bacteria (blue-green algae); these may attach before or after bacterial proliferation. These organisms, taken together, form what is known as the "primary film", a biotic layer long observed to be a necessary precursor to the settlement in significant numbers of larger fouling organisms (although macrofouling organisms such as barnacles and algae may settle upon submerged objects before the development of a primary layer). Henschel and Cook (1990) demonstrated that the requirement of a primary film for settlement by larger fouling organisms differed with species and with distance from established, donor colonies.

Hull surfaces historically developed massive fouling communities, with layers of seasquirts, hydroids, and seaweeds a third of a meter or more thick. Such communities on ships appear to be rare now, as discussed below. Since World War II heavily fouled barges may represent the modern-day analogue of older fouled ships. Doty (1961) reviewed the "Yon 146" incident of 1950, when this barge was towed from Guam to Pearl Harbor with extensive fouling communities which were subsequently sampled in drydock. Non-native species of fish, crabs, and benthic snails (the latter including species not typically associated with fouling communities) were found on the barge.

Anchors and chains left in the water for a period of time will become fouled. Once pulled out of the water and exposed to air, these sublittoral organisms, not adapted to exposure, such as subtidal species of barnacles, hydroids, bryozoans and similar organisms would presumably desiccate and die; wave splash on the anchor would perhaps prolong survival, perhaps long enough for the organisms to survive on short distance voyages before the anchor were to be dropped again. In a similar manner, benthic organisms that would have crawled onto the anchor are likely to be washed away or dried out. Many small craft mariners have retrieved their anchors after an overnight mooring to find a variety of bottom-dwelling organisms temporarily attached, ranging from crabs and snails to the more unusual chitons (Carlton, personal observation).

TABLE 3-2

VESSELS AS DISPERSAL AGENTS FOR AQUATIC ORGANISMS

ON THE OUTSIDE OF THE VESSEL

Type: **Fouling Organisms**
Attached organisms; associated biota (including benthic species) in fouling community; entrained organisms
Location: Hull, rudder, propeller, and anchor, and other submerged structures on any specialized vessel

Type: **Boring Organisms**
Wood borers and associated biota in tunnels and holes
Location: All below waterline wood structures: sheathing, keel, wormshoe, rudder

ON THE INSIDE OF THE VESSEL

<u>Accidentally transported</u>

Type: **Fouling Organisms** and associated biota in fouling community
Location: Sea chest, seawater pipe systems including intakes, anchor chains

Type: **Planktonic Organisms**
Location: <u>Water accidentally taken aboard</u>
Bilge water; chain locker water
<u>Water intentionally taken aboard</u>
Potable water
Live well water
Ballast water
Propeller shaft cooling water
Fire control water
Engine cooling water
Sanitary system water

Type: **Benthic Organisms**
Location: Sediments in tanks, holds, live wells and chain lockers

Type: **Maritime, marsh, benthic, intertidal, organisms**
Location: Solid ("dry") ballast (rocks, sand, debris), dunnage, and cargo in holds.

<u>Intentionally transported</u>

Type: **Fish and Shellfish**
Location: Live holding and bait wells

ABOARD THE VESSEL

Type: **Planktonic Organisms**
Location: Incidental water (in scuppers or other deck basins)

Type: **Benthic Organisms**
Location: In nets, traps, trawls, grabs; in scuppers or other deck basins

Type: **Fish and shellfish: living organisms for human consumption**
Location: Ship's galley

Type: **Aquaria (pets), seashells, curiosities**
Location: In company or private possession

There are three types of fouling organisms: those that are attached (sessile), those that are associated with this attached biota, and those that have been passively entrained by the vessel. Attached fouling organisms include sponges, hydroids, sea anemones, some species of worms, bryozoans, mollusks (mussels, oysters), crustaceans (barnacles, isopods, tubiculous amphipods), seasquirts and algae (seaweed). Some of these organisms can detach and re-attach, such as mussels, sea anemones, and hydroids. The associated biota of animals and plants found in these fouling communities can include hundreds of species from almost all phyla. Crisp (1973) has suggested that more than 4,000 species may comprise fouling communities on a worldwide basis. Benthic infaunal organisms also can be found in fouling assemblages on ships, a phenomenon considerably complicating interpretations of the biogeography of such species (examples include the softshell clam Mya arenaria, the salt marsh mussel Geukensia demissa, and benthic worms such as capitellids (Carlton, personal observations)).

MacGinitie (1938) made the unusual suggestion that another mechanism of dispersal relating to ship fouling communities existed. He demonstrated that some invertebrate larvae ingested by fouling-type organisms may be defecated alive, noting, "Today, with the great numbers of 'foul bottom ships' passing along the coast of all countries, a means of distribution is provided for practically all forms of larvae of estuarine animals. Since [the shipworm] Teredo and other pelecypod [bivalve mollusk] larvae are able to withstand trips through the alimentary tracts of other animals, they may be thus conveyed long distances from their place of origin."

Entrained organisms are those that may become entangled on structures external to the ship. On ocean-going vessels entrapment may occur on anchors and (on some sailing vessels) bobstay chains. Transport may occur for hundreds or thousands of kilometers before the organisms are washed off by heavy seas. On recreational vessels organisms may become entangled on the trailers used to transport the watercraft between bodies of water. Most common are algae (seaweeds), aquatic plants, and the organisms occurring on these substrates. Carlton (personal observations, 1992) has observed the fucoid alga Ascophyllum nodosum transported for 14 days entrained at the base of a bobstay chain on board a staysail schooner offshore from Maine to Massachusetts, surviving sea state conditions of Beaufort 7, for a distance of about 600 kilometers (375 miles). A little known phenomenon is that holoplanktonic organisms may be entrained in fouling communities while the vessel is underway, such assemblages acting as "nets" or "filters" (Carlton, personal observations, thecosome pteropods in the fouling communities on the aircraft carrier USS Hancock). Cheng (1989) noted that ship-mediated dispersal is one of several hypotheses to explain the unusual distribution of what may have been originally a solely Pacific species of the marine seastrider Halobates with populations now in the Atlantic Ocean. Cheng noted that this unique insect may have laid its eggs on ships' hulls and so been transported from the Pacific to the Atlantic. This phenomenon could have been enhanced by the entrainment of Halobates amongst heavy fouling assemblages.

A very unusual method of entrainment, and one which we have not seen previously reported, involves square-sterned vessels, such as LASH cargo ships, which create rolling turbulence in their wake. One captain reported to us that he observed the same piece of wood (presumably identified by unique markings) in the wake of his vessel at the end of an interoceanic voyage -- in this case, from New Orleans to Bangladesh, a distance of 19,000 kilometers (12,000 miles). He noted that this was "not uncommon". Investigations of the possible survival of attached and wood-boring organisms in such entrained pieces would be of some interest.

Canadian (Scales and Bryan, 1979; Dove and Malcolm, 1980; Dove and Wallis, 1981; Dove and Taylor, 1982) and New Zealand (Johnstone et al., 1985) studies have documented the

role of recreational vessels and trailers in the lake-to-lake transport of aquatic macrophytes. The role of recreational vessels and trailers in the intracontinental dispersal of zebra mussels (Dreissena) is now under study (Johnson and Carlton, 1993).

Boring organisms attack wooden structures below low tide line (on fixed structures) and below waterline (on floating structures, such as wood floats and vessels). Wood borers include shipworms, which are worm-shaped bivalve mollusks related to clams and mussels. Shipworm genera important in boring and destroying wooden ships and shallow-water wooden structures include Teredo, Bankia, and Lyrodus. The present day distributions of many shipworm species may represent the long shadow of maritime history. Similarly, the tiny isopod crustacean Limnoria, known as the "gribble", can be equally destructive in destroying wooden structures. Additional wood destroyers include boring clams (pholads) and burrowing amphipods (Chelura). Until the end of the 19th century shipworms and gribbles were globally distributed by shipping. Remaining wooden vessels at the end of the 20th century include historic vessels (those in the water) at maritime museums, tall ships still actively sailing, wooden-hulled naval minesweepers, and many smaller fishing and recreational vessels. Poorly maintained small wooden utility and fishing vessels in tropical waters are typically infested today by shipworms, and may frequently and unceremoniously sink at anchor or at the dock as a result (C. Fay, personal communication, 1992). Wooden yachts infected with shipworms in tropical waters may carry such species north to colder waters, and infestations may result within the thermal effluents of power plants. Thus the tropical shipworms Teredo bartschi and Teredo furcifera have appeared in the warm-water effluents of power plants in Barnegat Bay, New Jersey and in Long Island Sound at Waterford, Connecticut (Carlton, 1992b). Transoceanic and interoceanic dispersal of shipworms and gribbles may continue today through the transport of larvae and juveniles/adults, respectively, in ballast water.

The bore holes and burrows of these organisms provided habitat for many associated organisms, ranging from obligatory shipworm and gribble symbionts and commensals (Carlton, 1979a) to general fouling organisms and errant (vagile) organisms. Indeed, shipworm and gribble galleries, particularly those that had become enlarged through the collapsing of multiple burrows, may have provided deep, recessed habitats for many organisms, such as fish, shrimp, crabs, snails, errant worms, and echinoderms (seastars, sea urchins, sea cucumbers), not normally associated with ship fouling communities (Carlton, 1992a). Such phenomena may explain the early global movements of the European shore (green) crab Carcinus maenas (Carlton et al., 1993).

The exterior of vessels has thus historically provided perhaps the longest term, most fundamental vector for the dispersal of marine organisms. The modern-day manifestation and importance of this phenomenon are difficult to assess for several reasons: (1) changes in shipping over the past century (discussed below) would suggest that the predominance of hull fouling communities may have declined, (2) there are few modern post-transport studies of ship-fouling communities, and (3) there is considerable difficulty in distinguishing the role of ship fouling from ship ballast water as the effective dispersal agent for some species. Carlton and Hodder (1993) present a detailed, port-by-port description of the recruitment and fate of fouling communities on the Golden Hinde II, a replica of a sixteenth century sailing vessel, as it sailed off Oregon and California from Yaquina Bay to Coos Bay to Humboldt Bay to San Francisco Bay, but these data, at the Hinde's slow speeds of 4 to 5 knots and with port residencies of about 30 days, are more valuable as an insight into historical patterns of vessel-mediated dispersal than for understanding modern-day higher-speed, low port residency transits. Nevertheless, this rare data set from the Golden Hinde II provides important insights into the dispersal of organisms not normally associated with fouling communities (such as large benthic nudibranchs), on the intracoastal dispersal of native, coastal organisms, and on the differential morphological characteristics of

errant species that do and do not get washed off the vessel while at sea.

Changes in shipping relative to the role of vessels in transporting marine organisms have been discussed by Carlton and Scanlon (1985) and by Carlton (1992a). These changes include:

(1) *Increased vessel speeds* throughout the 19th and 20th centuries. Increased speeds would lead to more organisms (in terms of both species and numbers) being washed off the vessel as compared to earlier, slower voyages (ironically, it is this increased speed -- leading perhaps to decreased external biota -- that may be linked in part to the greater success of ballast as an invasions vector, since (as discussed elsewhere) the ballast water would now be in shorter transit, thus *increasing* the survival of ballast biota).

(2) *Decreased port residency time.* Decreased time in port would lead to decreased colonization of the vessel by the larvae or other dispersal stages of fouling organisms. Those species that do settle may have a greater likelihood (than adults) to be washed away because of the vessel setting out to sea within a short time after larval settlement and before they are firmly attached.

(3) *Increased use and efficacy of toxic antifouling paints.* Decreased settlement would lead to smaller fouling biomasses, and, concomitantly, fewer additional associated species in the fouling community. Hutchings et al. (1987) have noted that increased fuel costs and the importance of shorter in-transit times between ports "forces the shipping companies to ensure the hulls are kept clean with regular dry docking and to use modern effective anti-fouling paints". (It would be of interest in this regard to examine the changing history of dry docking frequency to examine this hypothesis).

(4) *Increased frequency of hull cleaning.* As noted in (3) driving economic forces would (or should) lead to greater vigilance in vessel cleaning. We have located no quantitative data to substantiate this hypothesis, and studies would be of particular value here.

These four phenomena combined would suggest that the dispersal of fouling organisms by vessels may have declined steadily throughout the 20th century. While there is little doubt that the frequent widespread movement of massive fouling communities on the bottoms of ships has declined, six additional phenomena suggest that ship-mediated dispersal of fouling organisms still occurs on a regular basis:

(1) Fouled vessels still travel upon the world's oceans. Selected regions on most vessel's hulls experience antifouling paint failure. Regions of the vessel that were not painted while in the yard (such as those hull sites resting against wood blocks in the yard, or small, tight spaces) may quickly become colonized by barnacles and hydroids while the vessel is in coastal waters (colonizers at sea include oceanic barnacles such as Lepas and Conchoderma). Where antifouling paint has been scraped off by the vessel rubbing against docks, pilings, fenders, and lock walls fouling colonization may proceed rapidly. Thus algal populations (composed of Bangia, Chaetomorpha, Porphyra, and Enteromorpha) and barnacles (Balanus) have been observed flourishing in waterline fouling of bulk woodchip carriers

arriving from Japan on the Pacific coast of the United States at the end of a 17 day voyage (Carlton, personal observation). Extensive fouling communities can always be seen growing on the hulls of fishing and recreational craft in marinas and harbors, but what remains in these assemblages after coastal voyages is largely unknown. Modern studies that examine the species composition of ship fouling communities at the end of coastal, transoceanic, and interoceanic voyages would be of extraordinary value in assessing the importance of this phenomenon as potential agents of biological invasions.

(2) Slow moving vessels still regularly cross the world's oceans, including towed barges, floating dry docks (such as the 254 meter (833 foot) *USS Machinist*, which was towed in May 1992 from the Subic Bay Naval Base to Pearl Harbor), and semisubmersible exploratory drilling platforms, all at speeds that may be very conducive to the survival of many fouling organisms.

(3) Ballast water can transport the larval, juvenile, or adult stages of most organisms that have classically composed the fouling community on a ship's hull. Barnacle (Balanus) and mussel (Mytilus) larvae are particularly common in ballast water (Carlton and Geller, 1993). Curiously, at least four species of seasquirt larvae and newly settled juveniles have been taken from 11-13 day old ballast water (Carlton and Geller 1993), making the attribution of ship fouling as the necessary agent for the appearance of the European seasquirt Ascidiella aspersa in southern New England in the late 1980s less certain. While it may be more likely that successful inoculation would occur as the result of the transportation of large numbers of adult seasquirts in fouling communities, as opposed to tadpole larvae released from ballast water, too little is known about what mediates such invasions to rank one dispersal vector over another.

(4) Certain organisms have evolved populations that are now resistant to copper-based antifouling paints, a phenomenon that Russell and Morris (1973) have referred to as "ship fouling as an evolutionary process". The fouling brown seaweed (alga) Ectocarpus siliculosus is the best known example of this adaptation (Russell and Morris, 1973; Hall et al., 1979; Hall, 1981).

(5) The greater ocean-going speeds of vessels has effectively decreased the length of time oligohaline-euryhaline species may be submerged in full-strength seawater, an argument Roos (1979) has invoked to explain the relatively recent global expansion of the Eurasian brackish water hydroid Cordylophora caspia.

(6) In years of global economic depression, there may be decreased investment in vessel maintenance, in order to maximize short-term profits. Many vessels are also now operated by management companies, and their contracts with owners are of such a short nature that investments to maintain vessels in adequate condition are not made (Anonymous, 1992a). In these cases, greater fouling would be expected. (Ironically, reduced maintenance may lead to increased fuel consumption and/or longer transit times).

Since the 1950s a number of new invasions of exotic estuarine and marine organisms have been recorded from American shores (Table 3-3), offering evidence that the role of vessel fouling

TABLE 3-3

EXAMPLES OF MARINE AND ESTUARINE INVASIONS IN U. S. WATERS SINCE THE 1950s POTENTIALLY RELATED TO TRANSPORT IN VESSEL FOULING COMMUNITIES

Species (Origin)	Year First Collected and New Location	References and Comments
Japanese Green Algae <u>Codium fragile tomentosoides</u> (probably transported from Europe)	1957: Long Island Sound; as of 1993: Maine to North Carolina	Carlton and Scanlon, 1985. An abundant fouling weed on pilings, floats, rocks, shellfish, and vessels.
Asian Seasquirt <u>Styela clava</u> (probably transported from Europe)	1973: Long Island; as of 1993: Maine to New Jersey	Carlton 1987; Berman et al., 1992. A very abundant fouling organisms from Cape Cod to eastern Long Island Sound
MacDonald's Seasquirt <u>Diplosoma macdonaldi</u> (Origin?: southern U.S. waters?)	1980?: Cape Cod Canal MA; as of 1993: New Hampshire to Long Is.Sound	Unpublished records of R. Whittaker, J. Carlton, L. Harris. In fouling communities.
Jellyfish <u>Anomalorhiza shawi</u> (Philippine Islands)	1983: Kaneohe Bay, Oahu, Hawaiian Islands; as of 1993: not known	Cooke, 1984 (introduced as the attached benthic stage, known as the scyphistomae)
European Seasquirt <u>Ascidiella aspersa</u> (Europe)	1985?: Cape Cod -- Long Island; as of 1993: Cape Cod Canal to Noank CT	Unpublished records of J. Carlton, R. Osman, R. Whitlatch, and R. Whittaker; identified by Gretchen Lambert, 1992. Abundant fouling organism locally.
Japanese Red Algae <u>Antithamnion nipponensis</u> (probably transported from Europe)	1988: Long Island Sound; as of 1993: the same	J. F. Foertch, personal communication (1992); Common on shore substrates
Sea Squirt <u>Ciona savignyi</u> (Japan)	1980s: southern California harbors; as of 1993: the same	C. and G. Lambert (personal communication, 1991), common in fouling communities
Sea Squirt <u>Microcosmos exasperatus</u> (Indo-Pacific)	1980s: southern California harbors; as of 1993: the same	C. and G. Lambert (personal communication, 1991); in fouling communities
Charru Mussel <u>Mytella charruana</u> (Venezuela?)	1986: Jacksonville FL as of 1993: no longer present?	Carlton, 1992b; established temporarily in power plant effluent
Edible Brown Mussel <u>Perna perna</u> (Venezuela?)	1991: TX: Port Aransas and region; as of 1993: the same	Hicks and Tunnell, 1993; common on rock jetties

TABLE 3-4

EXAMPLES OF MARINE AND ESTUARINE INVASIONS IN U. S. WATERS SINCE THE 1950s POTENTIALLY RELATED TO TRANSPORT IN VESSEL FOULING COMMUNITIES: Alternative Dispersal Mechanisms

Species	Alternative Dispersal Mechanism (other than external fouling) on the Indicated Pathway and Time Period:
Codium fragile tomentosoides	Western Europe to Long Island, late 1950s: *No other mechanism likely.* Not transported to the Atlantic coast on commercial oysters, as widely stated (see discussion in Carlton and Scanlon, 1985).
Styela clava	Western Europe to Long Island, late 1960s or early 1970s: *Ballast water, as tadpole larvae or metamorphosed animals.* [With all listed seasquirts, transport in ballast water is newly indicated by the discovery of living benthic ascidian tadpoles and newly metamorphosed benthic ascidians in 11-13 day old ballast water; Carlton and Geller, 1993]
Diplosoma macdonaldi	Southern U.S. Atlantic coast (?) to Cape Cod, late 1970s to early 1980s: *Ballast water, as tadpole larvae or metamorphosed animals.*
Anomalorhiza shawi	Philippines to Hawaii, early 1980s: *Ballast water, as ephyrae larvae.*
Ascidiella aspersa	Western Europe to Long Island and Cape Cod, mid-1980s: *Ballast water, as tadpole larvae or metamorphosed animals.*
Antithamnion nipponensis	Mediterranean to Long Island, 1980s: *Ballast water, as fragments and whole plants.*
Ciona savignyi	Japan to southern California, 1980s: *Ballast water, as tadpole larvae or metamorphosed animals.*
Microcosmos exasperatus	Indo-Pacific to southern California, 1980s: *Ballast water, as tadpole larvae or metamorphosed animals.*
Mytella charruana	Eastern South America to Florida, about 1986: *Ballast water, as veliger larvae.*
Perna perna	Eastern South America to Texas, about 1990: *Ballast water, as veliger larvae.*

communities in transporting nonindigenous species remains a viable transportation pathway. As noted above, the potential for species to be transported either as fouling organisms or in ballast water (Table 3-4) continues to obscure the role of the former, particularly in the absence of modern studies on ship fouling communities.

Semisubmersible Exploratory Drilling Platforms (SEDPs)

The potential role of SEDP's in the transoceanic transport of nonindigenous species to U.S. waters should be noted. In the best-known incident to date in U.S. waters, large specimens of the Asian crab Plagusia dentipes were discovered on an SEDP several months after it had made a 61-day transpacific crossing from Japan to California (Benech, 1978); the crabs, and other Asian organisms, including the large seasquirt Halocynthia roretzi, survived on the platform for at least three years (S. Benech, personal communication, 1979). The SEDP, after accumulating a cross-section of southern California biota, eventually went to the Philippines. In a similar incident, Foster and Willan (1979) documented the arrival aboard an SEDP in New Zealand with a wide variety of Japanese marine organisms, including barnacles, fish, hydroids, and algae, and the crab Plagusia depressa tuberculata. Joska and Branch (1986) noted that the appearance in South Africa in 1986 of the European shore crab Carcinus maenas "was probably brought about by oil rigs, and not by ships".

SEDPs provide a unique potential means of long-distance transport of marine organisms. They are without significant precursors in maritime commerce. Unlike large barges that are towed port-to-port, SEDPs exist in (and accumulate biota from) outer coastal environments for extended periods of time. SEDPs have extensive underwater structures (Figure 3-1) which could (and often do) support massive fouling communities. Wolfson et al. (1979), Hardy (1981), Moss et al.(1981), Forteath et al. (1982), Gallaway and Lewbel (1982), and Lewis and Mercer (1984) provide insight into the biotic diversity of such fouling communities. Quantitative studies on the biota of foreign SEDPs arriving in U.S. waters would be of great value.

Organisms on the Inside of the Vessel

Accidentally Transported Organisms

(A) Fouling Organisms and Associated Biota

Fouling organisms also occur on the inside of vessels in areas that are exposed and/or connected to the external environment. Internal sites for fouling include the sea chest (the sea inlet box, or the suction bay) and seawater pipe systems, including intakes (Carlton, 1985, p. 332 reviews examples of such fouling). As with hull fouling communities, an associated biota can develop in these internal fouling communities, and potentially include scores to hundreds of additional species. Sea chests are often located at the "turn of the bilge", and there are usually paired inlets port and starboard (Schormann, 1990). The chest is covered with a hull plate drilled with small holes. In emergencies (where seaweed or ice would block the sea chest plate, for example), "high sea suctions", used on some vessels for ballasting and for the intake of main engine cooling water, are located two to three meters above the sea chest intake (Schormann, 1990).

A seemingly unusual incident relative to sea chest fouling in a cargo vessel in the tropical

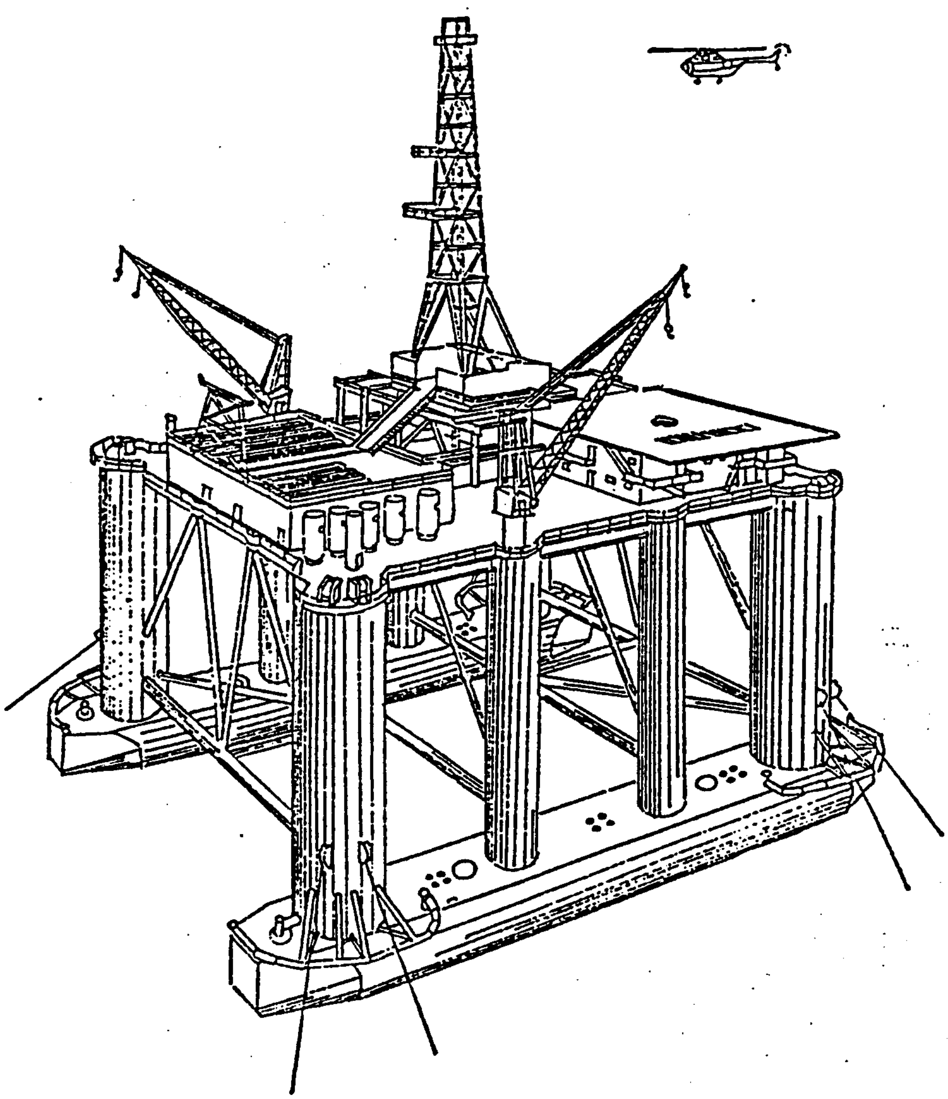


Figure 3-1

Semisubmersible rig, shown moored, with details of underwater structures (from Exxon Corporation (1980), The Offshore Search for Oil and Gas. Fourth Edition. Exxon Background Series, 20 pp.)

service leads to some useful general conclusions. Richards (1990) records the presence of the tropical muricid snail Thais blanfordi in the sea chests of a general cargo vessel sailing in the New Guinea archipelagoes. For several voyages the cruise track consisted of Saudi Arabia, Kenya, Malayasia, Singapore, and New Guinea, and then to Hull, England, via Hong Kong; the population structure of the snails (they were evidently reproducing in the sea chests) suggested that they had successfully survived British winter water temperatures before returning to the tropics. The snails had become abundant to the point that they had blocked the pipes and filters of the water cooling system.

Muricid snails have crawl-away young that emerge from deposited egg capsules; the absence of swimming planktonic larvae would suggest that young snails were drawn into the sea chests on floating seaweed or debris, and had survived (feeding on fouling barnacles) and grown to adults in these intakes.

Two observations may be drawn from Roberts' report:

(1) that sea chests may be the modern day manifestation of the deep, sheltered galleries of empty shipworm burrows in pre-20th century (wooden) vessels, in terms of offering a protected microhabitat on the vessel for organisms not normally associated with external hull fouling -- a habitat conducive to transportation because of the lower probability of being washed away at sea

(2) that the interpretation of the natural distribution of such organisms is further complicated by the advent of the sea chest in the evolution of the ship. The distribution of most organisms lacking a planktonic dispersal stage, and thus unable to be entrained and transported for long distances by ocean currents (or by ballast water) would generally be held to be natural (with the exception of species associated with commercial shellfisheries). Thais blanfordi is a species living on exposed reef habitats; Roberts suggests that the vessel may have "picked up" the snails near the barrier reef off Mombasa, Kenya. As this snail was carried into the vessel (by some unknown means), so it presumably could be carried out (unless they had grown too large to escape through the grate holes), and thus Thais potentially introduced to a new region.

As discussed above under external fouling, anchors can become fouled as well. Both the anchor itself and the anchor chain may be colonized by a variety of organisms, or the anchor and chain can entrain organisms (and sediment) and pull these up and out of the water. The entrainment of sediments by anchors is discussed below. Fouled anchor chain will be taken aboard and inside the vessel and automatically or manually deposited inside the "chain locker", an environment of widely varying humidity, oxygen, and temperature levels. The extent of the chain locker's ability to support life for extended periods of time is not known. For vessels that use their anchor on a daily or weekly basis on short-distance runs between many local harbors or ports, the movement of living organisms on the anchor chain is conceivable. Transportation on transoceanic or interoceanic voyages is less certain.

Carlton (1992c) has argued that fouled anchor chains were not the probable means by which the zebra mussel was introduced to North America, for the following reasons:

(1) vessels from Europe are more likely to have been tied up at docks (offloading cargo) rather than having been at anchor (except possibly for brief periods) before

departing for North America,

(2) most vessels either thoroughly wash sediments off incoming anchor chain with fire hoses or have built-in washing systems in the hawsepipes, in order to avoid any sediment accumulations in the chain locker,

(3) many mussels would be in a crushing environment as the chain passed through the hawsepipe, into the locker, and piled up onto itself,

(4) seawater may enter the chain locker through waves or spray, dousing these freshwater mussels with full salinity salt water.

In addition, four other European freshwater organisms (three fish and one crustacean), discussed elsewhere, whose only possible mechanism of introduction is ballast water also appeared in the same time period as did the zebra mussel in the Great Lakes.

(B) Planktonic Organisms in Water Systems

Schormann et al. (1990) recognized "four principal types of water" that can occur aboard vessels. These categories were:

Incidental water:	Rainwater, waves and sea spray breaking on deck, water used in deck lines, and bilge water collected in cargo holds and engine rooms
Potable water:	Drinking, shower, cooking, and galley washing water
Engine room water:	Cooling water and boiler make-up water
Waste water:	Ballasting and sanitary systems

We recategorize and recognize here ten principal types of water:

<u>Water accidentally taken aboard</u>:

(1) **Chain locker water**
Water taken aboard with anchor chains and collected and sometimes remaining in anchor lockers; or wave and spray water entering the chain locker. Locker systems may have bottom drains to the bilges. There are no published records of any samples taken in such water.

(2) **Bilge water**
Water collected in the bilges (through internal condensation, waves and sea spray, rainwater, anchor lockers, through-hull fittings, stuffing box leakages, etc.). Bilge water is generally not regarded as a site for living organisms in large ocean-going vessels (however, no records of samples are available). On small recreational vessels bilge water does carry living plankton (Johnson and Carlton 1993).

<u>Water intentionally taken aboard</u>:

(3) **Potable water**
Drinking, bathing, and galley water. Historically, water barrels carried aboard

sailing vessels have been suggested as the transport mechanism of the New Zealand freshwater hydrobiid snail Potamopyrgus antipodarum to Europe (Carlton et al. 1993), and of mosquitoes from Central America to the Hawaiian Islands. Large modern vessels take on water from urban supply systems, and this water is unlikely to be source of larger exotic organisms (but may contain viruses and bacteria).

(4) **Engine cooling water**

Water used in cooling the main power plant; these are usually flow-through systems and not likely to serve as long-distance transport mechanisms. Exceptions could occur with vessels that have water held in tanks and circulate cooling water internally, although heating of this water is presumably usually biocidal. Residual outboard engine water aboard small recreational vessels does contain living plankton (Johnson and Carlton, 1993).

(5) **Sanitary system water**

Sewage water. Bacteria, protozoans, and nematodes may occur in this water (see comments in Schormann, Carlton, and Dochoda 1990), as well as human viruses and helminths (trematodes and cestodes). Schormann (1990) stated that, "organisms such as (Chryso)chromulina and Gymnodinium could as easily have infected the Baltic and the Australian waters via malfunctioning sewage treatment plants [aboard ship] as they could via ballast tanks." There is, however, no evidence for this. There are no data indicating that these marine phytoplankton could survive in sewage water or that they occur in such water aboard ships. Sewage water has, in general, a much briefer residency period aboard most vessels, being flushed out once or twice per day throughout the transit period. Volumes of sewage water transported are very small compared to ballast water volumes. The equal probability noted by Schormann of sewage water and ballast water transporting these organisms is unlikely.

(6) **Live well water**

Water taken aboard in dedicated holds used to keep live fish, shellfish, or bait; these are also called wet wells or bait wells. Johnson and Carlton (1993) note the presence of living plankton in these wells in small recreational vessels. Carlton (1992d) discusses the role of live wells in larger, ocean-going fishing vessels. This mechanism, while often seeming innocuous, may play a far greater role than is generally suspected, *especially relative to intracoastal and intracontinental movements.*

(7) **Ballast water**

Water intentionally taken aboard and held in tanks or holds. We review ballast water in a separate section in detail, below.

(8) **Fire control water**

Water held in fire control lines. No biological data are available on this water type.

(9) **Propeller shaft cooling water**

Water is taken aboard some ships into aft peak tanks to be used as propeller shaft

cooling water. The plankton remaining in this water after a period of time is not known.

In addition, water may collect on the deck of a vessel and remain standing (without being washed overboard) for some length of time. This water is properly categorized as part of the "Aboard the Vessel" division (below), but we list it here as part of the total picture of water aboard a vessel:

(10) **Incidental water**

Waves and spray breaking over and onto the ship, and collected and remaining in the scuppers or other deck basins. On long trips of good weather, such water would usually dry up or, conversely, on trips of foul weather, be continuously flushed overboard. No data are available to document the role of incidental water in the transport of organisms.

(C) Benthic Organisms in Sediments

Sediment (mud (silt and clay), sand, or larger size fractions) and detritus may accumulate inside a vessel in a variety of holds, wells (including suction wells), tanks and lockers. Ballast sediments are discussed separately below.

Schormann et al. (1990) noted that sediments may enter chain lockers because of insufficient washings and remain in the damp environment of the locker. Redeployment of the anchor chain, or active overboard disposal of locker sediments, could theoretically lead to the release of exotic organisms. Little is known, however, about living organisms in chain locker sediments. Carlton (personal observation, 1992) examined mud that had been brought aboard on the unwashed anchor chain of the SSV Westward in Rockland, Maine and entered the chain locker. The mud was unintentionally brought back out onto the deck when the anchor was redeployed 13 days later in southern Massachusetts. Water temperatures external to the vessel varied from 11 to 27 degrees Celsius; chain locker temperatures are not known. Dried sediment samples that had dropped to the deck as the chain proceeded from the hawsepipe overboard were collected and rehydrated in 333um-filtered seawater. There were no living organisms; dried polychaete worms and benthic foraminiferans (Elphidium) were found in the mud.

Despite this limited observation, it remains possible that under certain circumstances of sufficient mud and water, in cold and/or humid conditions, some invertebrates would survive such transport for a similar length of time, if not longer. Candidate taxa would include dinoflagellates (as cysts), nematodes, ostracods, and many other taxa in their resting stages. Hawsepipe washing systems occasionally fail, and much sediment can accumulate in the locker. Foraminiferologists, for example, identifying species from Recent (Holocene) sediments (conservatively, post-15th century for regions under maritime exploration by that time, and post-18th century for much of the rest of the world) would need to take into serious account anchors and anchor chains in interpreting the modern distributions of marine and brackish-water foraminiferans (especially for those species that do not appear at the same localities in prehistoric sediments).

(D) Maritime, Marsh, Benthic, and Intertidal Organisms in Solid Ballast, Dunnage, and Cargo

Rocks, sand, debris, trash, detritus, soil, or any other materials loaded aboard a vessel to serve as ballast will almost always contain living organisms. Such materials have been referred to as "solid" or "dry" ballast (as opposed to water ballast). Little if any such ballast is used aboard

vessels today. Solid ballast was used from prehistoric times until the beginning of the 20th century; Carlton (1992a) briefly reviews some of this history. As a result, many terrestrial plants and animals were distributed around the world, as well as many benthic, intertidal, marsh, and maritime (drift, littoral, strand) species, although far less is known about this latter phenomena. The role of sand ballast in creating the modern day distributions of meiofauna (interstitial fauna, psammofauna) is virtually unstudied.

Packing materials, known as dunnage, to secure or protect cargo historically included terrestrial grasses, marsh grasses, seagrasses, dried seaweeds, mats, boughs, rattans, and wood. Such materials frequently may have contained living organisms such as plants, plant seeds, insects, spiders, other arthropods, earthworms, and snails. It appears that little or no modern day use is made of such materials (with the possible exception of wood pallets) in current international trade, although it would not be surprising to find such usage continuing among native peoples along the coastlines and among the islands of Eurasia, Asia, Australia, South America, and Africa.

Aquatic organisms may also be introduced in ship's cargo. Marchand (1946) described in detail how the Mexican saber crab Platychirograpsus typicus (as well as turtle, frogs, and snakes) were transported to Florida on and in cedar logs in the holds of cargo ships.

Intentionally Transported Organisms

(E) Fish and Shellfish

Living fish and shellfish (mollusks and crustaceans) are typically transported both short and long distances in the "live wells" or "wet wells" of both coastal and ocean going vessels. These species are intended for direct human consumption, or for transplantation and release in aquaculture-mariculture operations. This virtually unregulated movement of organisms has led to the introduction of both target (selected) and nontarget (other species accidentally mixed in with target species, as well as disease) fish into the Hawaiian Islands (Randall, 1987). In addition, as noted above, the water in such wells may contain planktonic organisms that would be released as well.

Organisms Aboard the Vessel

Four categories of organisms may be found aboard vessels. Little or no quantitative information is available for any of these phenomena.

(A) Planktonic Organisms in Incidental Water

Water taken aboard a vessel through waves and spray may accumulate in the scuppers or other depressions on deck. This phenomenon has been discussed above.

(B) Benthic Organisms

Benthic organisms captured by fishing vessels may remain on the deck of a vessel entrained in nets, traps, trawls, and grabs, or free on the deck in scuppers or other deck depressions. Such species may be transported hundreds or thousands of kilometers before being washed overboard. Carlton and Scanlon (1985) speculated that the Asian green algae Codium fragile tomentosoides may have been transported west to east around Cape Cod on fishermen's

nets. Uriz (1990) speculated that the unusual distribution of the sponge Suberites tylobtusca may be due to similar transport from the Red Sea to off the southwest coast of Africa.

(C) Fish and Shellfish: Living Organisms for Human Consumption

Living mollusks, crustaceans, and perhaps even fish may be carried by vessels for human consumption on board. It has been speculated that the appearance of the common Atlantic clam, the quahog Mercenaria, at Southampton, England, may have been due to the discarding of leftover living clams from the galley of an oceanliner.

(D) Aquaria (Pets), Seashells, Curiosities

Living organisms may be intentionally carried by crew and passengers on vessels in aquaria as pets and as curiosities. Seashells (particularly snails (gastropod mollusks)) may be transported great distances, later to be discovered still alive and therefore potentially released back in the sea. Wolff (1977) has noted that Polish fishermen returning from American waters kept living horseshoe crabs (Limulus polyphemus) aboard their vessels and released them into the North Sea.

Summary of Vessels as Dispersal Agents

In summary, fouling, boring, planktonic, and benthic organisms can be carried both inside and outside seagoing vessels of many types. Certain stages of boring organisms may be transported today inside vessels in ballast water or in wooden hulled vessels. Planktonic organisms may be transported on the outside of vessels when entrained in fouling communities, and benthic organisms may similarly be carried when they settle as larvae in hull fouling assemblages. The transport of maritime and marsh organisms, once widely distributed by ships in solid ballast and dunnage, may be rare today, with the exception of those species with planktonic larvae (such as pulmonate melampid gastropods with planktotrophic larvae).

Chapter 4.

SHIPPING AS A MAJOR PATHWAY OF TRANSMISSION OF NONINDIGENOUS SPECIES: BALLAST WATER AND SEDIMENTS

(A) A BALLAST PRIMER

Introduction and History

For all modern ocean-going vessels, ballast is water taken aboard to stabilize the vessel at sea and for a variety of other purposes (discussed below). A brief review of the terminology of ballasting and ballast water is presented in Box 4-1. The type of water ballasted is whatever water the vessel is in at the time of ballasting. Water may be fresh (0.5 parts per thousand (o/oo) dissolved salts or less), brackish (salt levels ranging from 0.5 to 30 o/oo) or salt (30 o/oo or greater) (Symposium on the Classification of Brackish Waters, 1959). Most ballast water will naturally contain living organisms and varying amounts (loads) of dissolved and suspended organic and inorganic compounds -- in short, whatever is in the water under the ship at the time of ballasting.

Although experiments with built-in ballast water tanks in vessels date from the mid-1840s, the use of water as ballast on a regional basis commenced in the 1850s with the "introduction" of built-in compartments in coal-carriers (colliers) trading between the Tyne River and London (Carlton, 1985). The advent of ballast water came about in order to reduce the time and expense in loading and unloading solid ballast. Over the next 20 to 30 years water ballast tanks became a more integral part of vessel design, but it was not until 1880 that Lloyd's Register began noting types and capacities of water ballast tanks. Regular transoceanic and interoceanic use of ballast water thus did not commence until approximately 100 years ago, although it is probable that it was not until during and after World War II that ballast water in appreciable volumes began to be moved around the world.

Why Ballast Water is Taken Aboard

Ballast water is taken aboard a vessel for a variety of reasons (Box 4-2). Vessel safety is the primary goal: proper ballasting (amount and distribution) reduces stress, provides stability, aids with propulsion and maneuverability, and compensates for weight lost from fuel and water consumption. Operational requirements frequently require a vessel to be lower in the water (requiring taking on of water) or higher in the water (requiring discharge of water). Altering the ballast condition of a vessel impacts one or more of these basic requirements.

Ballast Condition

"Ballast condition" (the amount and distribution of water) directly affects a vessel's performance at sea. In general, a vessel with too much ballast aboard is said to be in a "stiff" condition, with heavy laboring and potential loss of speed. A vessel with too little ballast aboard produces "crankiness" or "tenderness" and would have a greater tendency to capsize. The amount and distribution of ballast on board (**BOB**) and the reasons for ballasting are determined by the ships' officers, based on the specific vessel's operating manuals, with attention to national

BOX 4-1

THE TERMINOLOGY OF BALLASTING AND BALLAST WATER

OPERATIONAL STATES

ballast	to take on water for ballast aboard a vessel, by pump or gravitation. *Synonyms:* board, take on, load, fill, ballast up, pump up, pump in, flood
deballast	to remove water from a vessel, by pump or gravitation. Deballasting only is not exchange. *Synonyms:* discharge, take off, off load, pump out, pump down, unload, dump, drop
reballast	to take water back into the vessel after deballasting.
in ballast	with no cargo and with varying amounts of ballast water, often but not always near capacity.
with ballast	with cargo and some ballast water.
crank (tender)	to have "too little" ballast aboard, in the entire vessel or in some compartments only (less ballast than required for maximum stability but still within safe operating conditions; there may be some free surface in tanks); ship rolls more easily.
stiff	to have "too much" ballast aboard, in the entire vessel or in some compartments only (low or no free surface in tanks); ship tends to "snap" roll.
exchange	deballasting followed by reballasting. Most vessels reporting "exchange" usually mean partial exchange. *Synonyms:* flush, flow through, flush through, rinse
umpumpable	water that cannot be pumped out of a tank before suction is lost (for example, because the water is below the pump suction or held in pools behind tank baffles or other structures). *Synonyms:* dead water, empty
pressed	the tank filled to capacity, and perhaps overflowing. *Synonyms:* pressed up, capacity, full capacity
ullage	is the height of the space between the water surface and the top of the tank; ullage is zero when the tank is pressed.
permanent	water taken aboard to be held for a relatively long period. The water may be exchanged one or more times per year or not be exchanged for one or more years; materials other than water are used for permanent ballast as well.

BOX 4-1

THE TERMINOLOGY OF BALLASTING AND BALLAST WATER

(Continued)

TANKS

(see Table 4-1 for list of tank types)

arrival ballast	in oil tankers, ballast water taken aboard in cleaned cargo tanks.
departure ballast	in oil tankers, ballast water taken on board in uncleaned cargo tanks and later discharged overboard except for the upper layers which are actively pumped into "slop tanks".
segregated	tanks designed and only used for ballast water; segregated ballast tanks may be certificated by Lloyd's Register in accordance with MARPOL 73/78.
dedicated	cargo holds or tanks set aside to be used only for ballast water.
main, auxiliary	the two major types of ballast tanks aboard submarines: main tanks, used for vertical positioning, are either internal in the vessel's pressure hull, or external in the form of "blister" on the main hull; auxiliary tanks (also called trim tanks) are within the pressure hull, and are used for trimming while submerged.

WATER QUALITY

clean	in oil tankers, the ballast held in the cargo tanks after the oil cargo has been offloaded and the tank washed. Clean ballast is water "which has been so cleaned that the effluent therefrom does not create a visible sheen or the oil content exceed 15ppm" (Cowley, 1990). Regulation 1(16) of Annex 1 of MARPOL 73/78 provide further definition.
dirty	in oil tankers, the water added to cargo tanks before tank washing. *Synonyms:* unclean, oily, oily ballast

TABLE 4-1
DIVERSITY OF TANKS AND HOLDS USED FOR BALLAST WATER

The first tank type in each category below indicates the main type in that category. Additional tanks in that category are either subdivisions of the main type or represent an extension (for example, double bottom tanks and wing bottom tanks). Names in parentheses are synonyms. Most tanks, except peak and deep tanks, and cargo holds, are divided into equal-sized port and starboard compartments. Further division of ballast tanks can be extensive, resulting in 30 or more separate ballast tanks in some vessels, and up to 96 separate tanks in a modern container ship (LSD41 class).

DOUBLE BOTTOM TANKS (DBTs)	(Bottom Tanks)
Wing Bottom Tanks (WBTs)	(Lower Wing Tanks, Double Bottom WTs)
Double Bottom Wing Bottom Tanks (DBWBTs)	(Lower Wing Tanks)
Bottom Side Tanks (BSTs)	
Tunnel Tanks (TTs)	
WING TANKS (WTs)	
Upper Wing Tanks (UWTs)	(Top Wing, Topside, Topside Wing Tanks)
Lower Wing Tanks (LWTs)	(Double Bottom Wing Tanks, WBTs)
Flume Tanks (FT)	("Stability Tanks", may also refer to specific UWTs)
Heeling Tanks (HT)	
SIDE TANKS (STs)	
TOPSIDE TANKS (TSTs)	(Top Wing, Topside Wing, Upper Wing Tank, Shoulder Tank)
FORE PEAK TANK (FPT)	
Upper Fore Peak Tank (UFPT)	
Lower Fore Peak Tank (LFPT)	
AFT PEAK TANK (APT)	[APT is often used to carry drinking water or permanent cooling water for the propeller shaft]
Trimming Tanks	[Fore or Aft Peak or Deep Tanks; type of UWT or TST]
DEEP TANKS (DTs)	
Half Height Deep Tanks	
DECK TANKS (DKTs)	
Between Deck Tanks	('Tween Deck Tanks)
Underdeck Tanks	
COFFERDAM (CD)	[Found on some tankers; not normally constructed or used as a ballast tank. CDs are normally used as a drainage from the other tanks, although occasionally containing a large amount of seawater]
CARGO HOLDS (CH)	
[**Segregated** Ballast Tanks]	[Any tank in which only water is carried, usually applied to tankers]
[**Dedicated** Ballast Tanks]	[Unaltered cargo tanks used exclusively for ballast]

BOX 4-2

WHY BALLAST WATER IS TAKEN ABOARD OCEAN-GOING MERCHANT VESSELS

(Some of these operations apply only to specific vessels in specific situations)

(1) ***To diminish hull stress:*** Properly distributed ballast helps to counteract (to minimize) the forces on the hull of the empty or partially loaded vessel. Hull stress is described in terms of shear forces and bending moments, each of which has specific quantitative ranges that could or would lead to exceeding a vessel's ability to remain intact if the ranges were exceeded. Ballast water may also be used to counter the conditions of rising up midships ("hog condition") or flexing down midships ("sag condition") during loading and offloading operations.

(2) ***To provide proper stability and trim:*** Ballast is used (a) for trimming (to control fore-to-aft angle), (b) for stabilizing (to control side-to-side angle (list)), using flume (or stability) tanks to control roll, (c) to reduce free surface area in the tank or hold that would cause the water to rock back-and-forth and potentially cause instability or internal damage, and (d) to minimize slamming of a vessel at sea.

(3) ***To aid in propulsive efficiency:*** Ballasting controls the submergence level of the propeller and the bow thruster, and thus aids in controlling propulsion.

(4) ***To aid in maneuverability:*** Ballasting down brings a vessel lower in the water, thus submerging the rudder and reducing freeboard exposed to winds coming abeam of the vessel at sea; adjustment of trim and list aids in maneuverability.

(5) ***To compensate for the consumption ("loss") of fuel and potable water:*** Ballasting provides weight compensation as fuel and water are consumed.

(6) ***To provide for operational needs (proper draft):*** Many ports and shoreside industries have specific draft requirements that require ships to have more ballast water aboard (in order to get under loading cranes or chutes, or in order to navigate under bridges) or less water aboard (in shallow port channels or berths). During loading operations, bulkers, containers, car carriers, RoRos, and other vessels will continually adjust their ballast to maintain a proper relationship with derricks, cranes, container tracks, car ramps, and so forth.

(7) ***To provide for increased comfort at sea under weather conditions:*** Ballast may be taken aboard to reduce the roll of the vessel in order to increase passenger and crew comfort, and to reduce damage to cargo, independent of other stability needs. High tanks (for example, wing tanks and topside tanks) are normally used for this purpose (T. Fleck, personal communication, 1991).

(8) ***To clean decks and holds:*** Ballast water (particularly freshwater ballast) may be used to wash down deck surfaces and holds; this water would then have to be replaced, and additional ballast taken aboard.

(American Bureau of Shipping, U.S. Coast Guard) and international (Lloyds, various Classification Societies) requirements for the proper maintenance of the stability of the vessel at sea. Vessel stability and ballasting are covered extensively in the literature and are outside the scope of the present study.

How Ballast Water is Taken Aboard

Ballast water is pumped aboard a vessel from several meters below the water line with dedicated ballast pumps. The same pump and the same external hull openings are used to take water into (fill or ballast) and remove (discharge or deballast) water from a vessel. The ballast intake is covered with a steel plate (a grate or strainer) with numerous holes of 1.0 to 1.5 cm diameter. These plates are often rusted through in part, creating openings of several hole diameters combined. Water may be gravitated in or out of a particular tank or hold but not generally both gravitated in and out of the same hold. Tanks above the waterline (for example topside tanks) would require that water be pumped in but these may be emptied by gravitation. Tanks below the waterline (for example, double bottom tanks) can be filled by gravitation, but would need to be pumped out to be emptied. It may be possible by pumping the ballast in different tanks to both gravitate at least some portion of the water into and out of a particular tank, but some pumping would still be required elsewhere.

Some vessels have automatic ballasting systems. Many container ships have what may be the most advanced computer-interfaced ballasting operations of any modern commercial seagoing vessel, with ballasting requirements being automatically determined based upon changing cargo loads.

Reported ballast pump capacities vary from 75m^3/hour (NABISS data) to 2500m^3/hr (Pollutech, 1992). Among 48 vessels the largest pump type we encountered was 1000m^3/hr; the majority of vessels possessed pumps of 150-350m^3/hr (n = 17 vessels) and 600m^3/hr (n = 11 vessels). In 159 woodchip bulk carriers (Japan -- Pacific Northwest route), in the 40,000 - 50,000 DWT range, ballast pump capacities ranged from 780 to 975m^3/hr (Carlton et al., 1993b). Many modern container ships have pump rates of about 500m^3/hr (about 132,000 U.S. gallons/hr). Vessels with a single pump aboard with a pump capacity of 2500m^3/hr (chosen as an average pump rate for control option costing purposes by Pollutech (1992)) would be rare. A pump rate of 600m^3/hr corresponds to 158,500 U.S. gallons/hr; of 1000m^3/hr, 264,000 gallons/hr, and of 2500m^3/hr, 660,500 gallons/hr.

Why and Where Ballast Water is Discharged and/or Exchanged

Ballast water may be discharged or deballasted from (pumped or gravitated out of) a vessel, followed in some cases by immediate reballasting (deballasting plus reballasting is the *exchange* of ballast water), for the reasons given in Box 4-3. Deballasting to reduce the vessel's stiffness, for weight compensation as loading proceeds, and to navigate in shallow channels are industry-wide practices. Altering ballast condition for temperature, bulkhead, or fuel temperature compensations, to influence speed, or for water quality or sediment management are more specific to individual types of vessels, ballasting locations, trade routes, and are less industry-wide. In reality, officer experience, habits, and desires, aboard vessels with unique situations and ballasting characteristics, frequently dictate the actual ballast condition which a ship is in.

BOX 4-3
WHY WATER IS DEBALLASTED AND/OR REBALLASTED ABOARD OCEAN-GOING MERCHANT VESSELS

(Other than as mandated by ballast water exchange requirements for control of the introduction of nonindigenous species)

(1) ***Weight compensation:*** A vessel would deballast when taking on sufficient cargo, equipment, fuel, water, or personnel. Vessels will *deballast* in the port or harbor as loading proceeds or, anticipating loading and desiring to save time at the port of call, *deballast in calm seas while inbound for the harbor* (deballasting may commence in some cases 10 to 12 hours or more before port arrival). Vessel may *reballast* later in the loading process, or after loading is complete, to achieve proper trim before departure.

(2) ***Port Draft Requirements:*** Specific maximum draft requirements in a port may require that vessels have less water aboard. A vessel may thus *deballast* while proceeding into or within the port. Adjustments to ballast load may occur at the dock as cargo loading/unloading proceed.

(3) ***To Compensate for Density Changes in the Surrounding Water:*** A vessel moving from fresh water to salt water may take on ballast to compensate for increased buoyancy, while a vessel moving from salt water to fresh water may discharge water. Temperature changes may be sufficient to affect water density as well.

(4) ***Ballast Water Temperature Control:*** A vessel with freshwater ballast (as from the Mississippi River) headed into northern latitudes may change water to avoid ballast freezing.

(5) ***Compensation for Internal Condensation:*** A vessel sailing into warmer latitudes with colder ballast water may experience condensation on adjoining bulkheads and in cargo holds, and change ballast for warmer ambient waters accordingly.

(6) ***Compensation for Fuel Thickening:*** A vessel with colder ballast water held in tanks adjacent to fuel tanks may experience cooling and thickening of the fuel, and change ballast for warmer ambient waters (if available) accordingly; this warms the fuel faster than the original colder ballast can come up to ambient sea temperatures.

(7) ***Increase speed in calm seas:*** In calm weather, a vessel may deballast to lighten its weight and increase at-sea speeds and decrease fuel consumption.

(8) ***Discharge of polluted ("foul") water:*** Water taken up in a port or harbor and known or suspected to be polluted may be exchanged at sea for "clean" ocean water.

(9) ***Discharge of sediments:*** Water with high sediment (mud (silt and clay)) loads may be exchanged for open ocean water. It is a practice aboard container vessels, for example, to exchange ballast water (in a tank-by-tank fashion) after leaving from sediment-laden harbor waters, taking advantage of the "natural roll" of the vessel at sea to keep the mud in suspension during deballasting (D. Nemeth, personal communication, 1992).

Potential Patterns of Where Water is Ballasted and Where it is Released

A critical concept in ballast water management is that the source regions and release sites of ballast water can occur in a complex fashion along the vessel's route. In the following discussion, "point" refers to a stationary site of ballasting and "enroute" refers to ballasting while the vessel is underway.

Ballasting patterns can be as follows: point/point, point/enroute, enroute/enroute, enroute/point, and all other combinations (e.g., point + enroute: enroute + point). In effect then one vessel may ballast as follows:

Site A : Port of origin (point)
Vessel is ballasting up prior to departure (and may still be carrying ballast from previous ports)

Site B : Inshore (neritic) or offshore waters (enroute)
Vessel continues to ballast while underway

Site C : Open ocean waters (enroute)
Vessel takes on or discharges water for trim and/or stability, or undergoes exchange

Site D : Inshore waters near destination port (enroute or point)
Vessel takes on or discharges water for stabilization in heavy seas, for passing under bridges, or for standing by near docks or at anchorage while awaiting berth

Site E : Destination port (point)
Vessel takes on or discharges water to compensate for cargo loading or unloading

One vessel may thus have water from multiple sources, unmixed and mixed within the ship, with different water in different tanks. Biologically, this translates to the vessel accumulating organisms from all multiple ballastings at many sites. It is thus important to note that organisms in arriving ballast water are not necessarily strictly estuarine or coastal in origin.

Container ships represent perhaps one of the best examples of the constant -- virtually daily -- movements of ballast water, typically taking up and discharging some quantity of water, in a "Johnny Appleseed" ("Johnny Clamseed") fashion, wherever they go. Table 4-2 presents examples of such water movements in two ships in the Pacific Rim trade. These data represent recent vessel transits as transcribed by us from the ship's arrival/departure condition reports when we boarded the vessel (NABISS/NV data).

In practice, vessels may actively avoid ballasting under certain situations. These include, (1) avoidance of ballasting up water with high sediment loads (to avoid sediment accumulation and the additional weight, to avoid removal costs, to avoid shallow ballast tanks filling with sediment, and to avoid the uptake of sulphate reducing bacteria, the main cause of microbially-induced ballast tank corrosion (Anonymous,1992b) and (2) avoidance of ballasting up what is known or believed to be polluted water (to avoid subsequent clean up costs in the tanks). A

TABLE 4-2

BALLAST WATER AND CONTAINER SHIPS: EXAMPLES OF BALLAST WATER MOVEMENT PATTERNS

LPOC	Last Port of Call
PPOC	Present Port of Call
NPOC	Next Port of Call (*)
+	Ballast water taken on
-	Ballast water discharged
*	Boarded by NABISS
SDWT	Summer Deadweight Tonnage
BWCAP	Ballast water capacity
BOB	Ballast on Board (MT)
MT	Metric tons

Container Ship #1
Registry: Liberia
SDWT: 44477 MT
BWCAP: 10453 MT

LPOC: Oakland
PPOC: Long Beach
NPOC: Hong Kong

Date (1992)	Location	BOB(MT)	+/-
------	Long Beach	----	---
13 May	Hong Kong	6032	---
14	Hong Kong	6350	+318
17	Singapore	6518	+168
18	Singapore	6477	-41
18	Port Kelang	6477	
19	Port Kelang	5280	-1197
20	Singapore	5280	
20	Singapore	4614	-666
24	Hong Kong	4614	
25	Hong Kong	5324	+710
5 June	Oakland	5378	+54
6 June	Oakland	5234	-144
7 June	Long Beach	5225	-9
*9 June	Long Beach	4125	-1100

Port	Country
Port Kelang	Malaysia

Container Ship #2
Registry: Taiwan
SDWT: 53274 MT
BWCAP: 19240 MT

LPOC: Jamaica
PPOC: Los Angeles
NPOC: Tokyo

Date (1992)	Location	BOB(MT)	+/-
24 March	Los Angeles	6565	---
27	ocean	6585	+20
7 April	Tokyo	6110	-475
8	Osaka	5060	+1050
10	Pusan	5020	-40
13	Keelung	6701	+1681
15	Kaohsiung	6701	
17	Hong Kong	6350	-350
21	Singapore	6300	-50
24	Colombo	3200	-3100
12 May	Hamburg	5350	+2150
13	Thamesport	5350	
15	Rotterdam	5350	
16	Antwerp	8580	+3230
26	New York	11970	+3390
27	Norfolk	10686	-1284
29	Charleston	5460	-5226
1 June	Jamaica	5460	
*11	Los Angeles	8170	+2710

Port	Country
Keelung	Taiwan
Kaohsiung	Taiwan
Colombo	Sri Lanka

third site-specific reason for altering ballast operations has been proposed by Australian scientists and advocated by the International Maritime Organization (IMO): avoidance of regions known to be sites of harmful phytoplankton (toxic dinoflagellate) species. We expand this latter concept to a broad "Global Hotspot Program" herein.

Some vessels reported taking on freshwater as ballast from the city water supply system, to avoid taking on polluted water or sediment-laden water, or to avoid tank corrosion and thus reduce maintenance. NABISS national port and vessel surveys found this practice to be rare, however.

The movement and release patterns of ballast water are such that no coastal sites, whether they receive direct shipping or not, are immune to ballast-mediated invasions. Workers have occasionally assumed that locations that are not major ports are not likely to receive ballast water-mediated introductions. Four factors complicate this interpretation: (1) ships may release their water as they pass along coastlines, sufficiently inshore that onshore advection (transport) may carry meroplankton or holoplankton into small lagoons or bays or any other coastal location, (2) ships may release their water at major ports, but species may be subsequently transported on coastal currents to adjacent coastal sites away from the harbor, (3) coastal vessel traffic, including barges, small fishing boats and sailing boats, may disperse species from initial sites of release to small embayments, marinas, and so forth, and (4) other commercial activities, such as aquaculture (mariculture), may inadvertently transport species to distant locations. The presence of an exotic species in a small estuary or lagoon far from major commercial ports thus does not in and of itself necessarily mean it (or, of course, its parental predecessors) was not initially introduced by ballast water to the region in general.

Ballast Tanks and Capacities

Water is carried by a vast variety of vessels (Table 3-1) and held in an impressive variety of tanks or holds (Table 4-1). Figures 4-1, 4-2, and 4-3 illustrate different ballast tank configurations in a general cargo ship, container ship, bulk carrier, ore carrier, tanker, and RoRo cargo carrier. The advent of *segregated* and *dedicated* ballast tanks came about through national and international efforts to reduce the discharge of oily ballast in the ocean. Oil and water do not mix in these tanks. Segregated ballast tanks are those in which only water is carried; these always have separate ballast piping. Dedicated ballast tanks are unaltered cargo tanks used exclusively for ballast (Carlton, 1985; Curtis, 1985). *Permanent* ("locked in") ballast may be solid ballast (lead, pig iron, drilling mud, concrete, etc.) often placed lengthwise above the keel of the vessel or may be water ballast that is rarely changed (*semi-permanent*).

Ballast capacity can range from hundreds of gallons in sailing boats (Nouse, 1988; Callahan, 1991) and fishing boats (NABISS data) to tens of millions of gallons in commercial cargo carriers (Tables 4-3 and 4-4). There is no international standard on the unit of measurement reported for ballast capacities; these are variously given in metric tons, short tons, long tons, cubic meters, U. S. gallons, or Imperial gallons and barrels. A Capesize bulk carrier may carry up to 75,000 MT (about 19,800,000 gallons) of ballast water (Hill, 1990). An ore carrier travelling from Europe to Brazil may carry up to 120,000 MT (about 32,000,000 gallons) of ballast water (Captain K. Kiyota, Master, M/V Keisho Maru, personal communication, 1989). Tankers with similar ballast capacity travel to Valdez (NABISS/APHIS data). Jones (1991, p. 9) notes that a large cargo vessel in the Australian trade has a ballast water capacity of 140,000 tons (about 37,000,000 U.S. gallons). A large oil tanker travelling from North America back to the

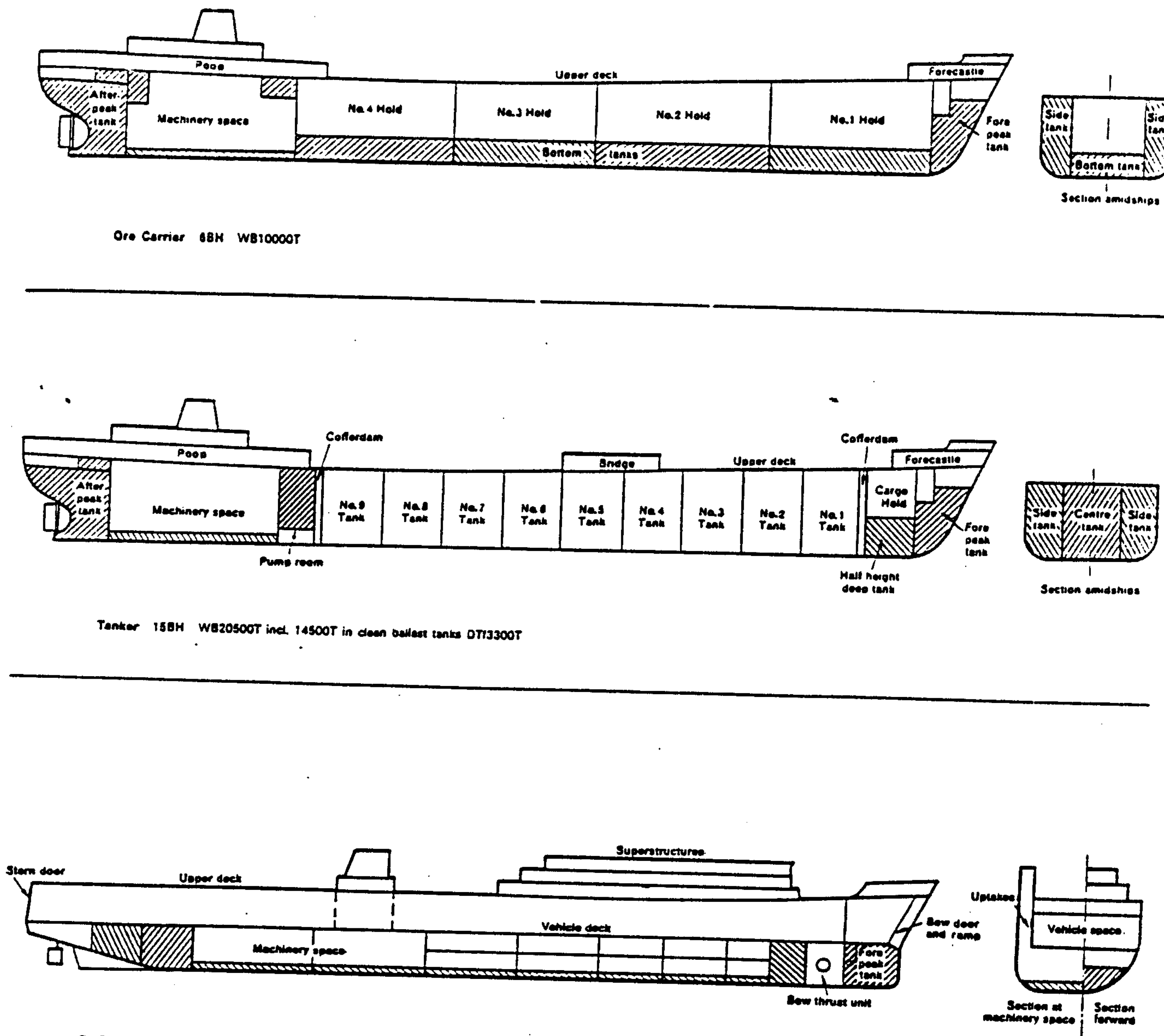


Figure 4-1

Structural Profile (including Ballast Tanks)
of an Ore Carrier, Tanker, and Ro Ro Cargo Vessel
(from Lloyds Register)

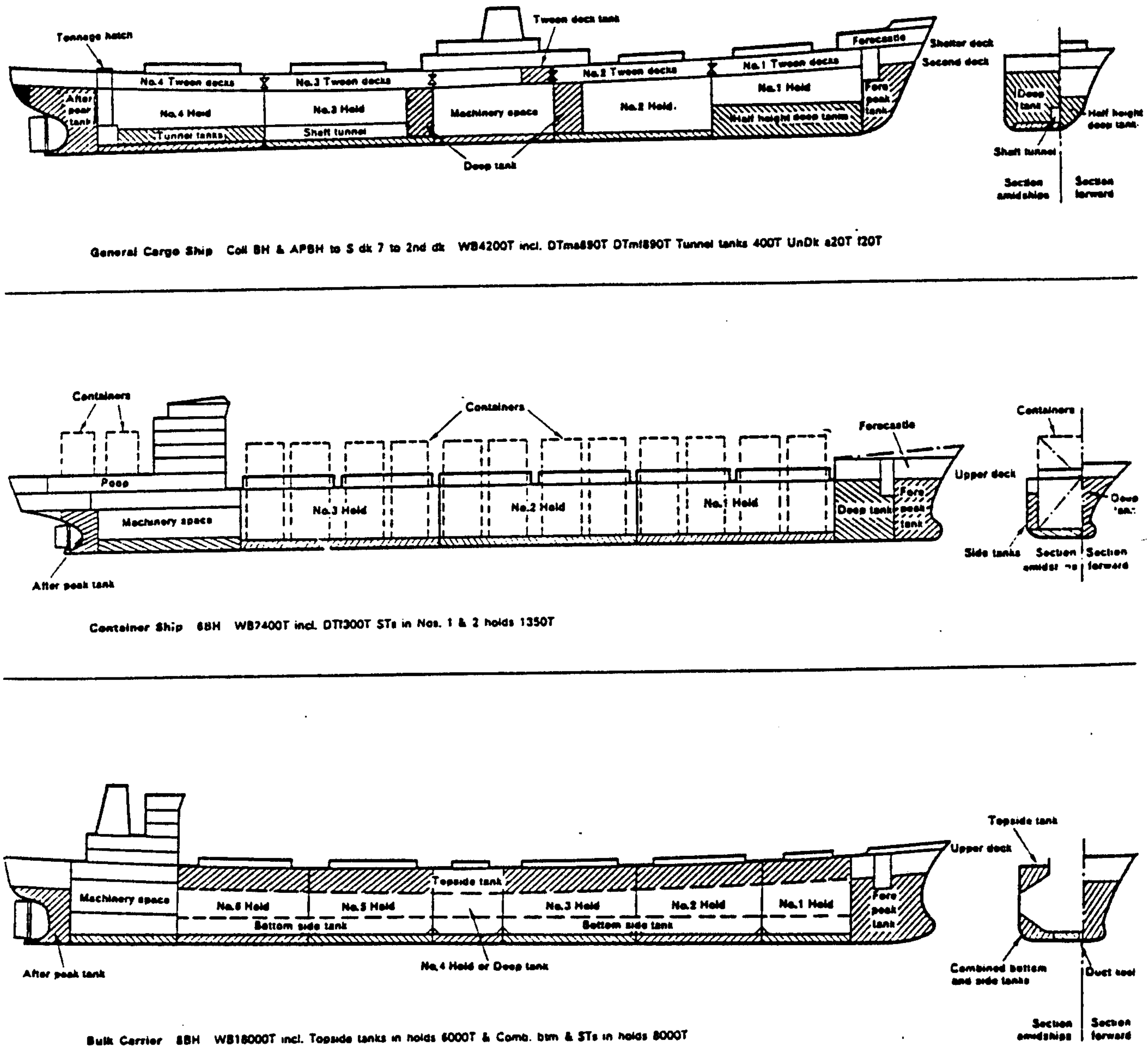


Figure 4-2

Structural Profile (including Ballast Tanks)
of an General Cargo Ship, Container Ship, and Bulk Carrier
(from Lloyds Register)

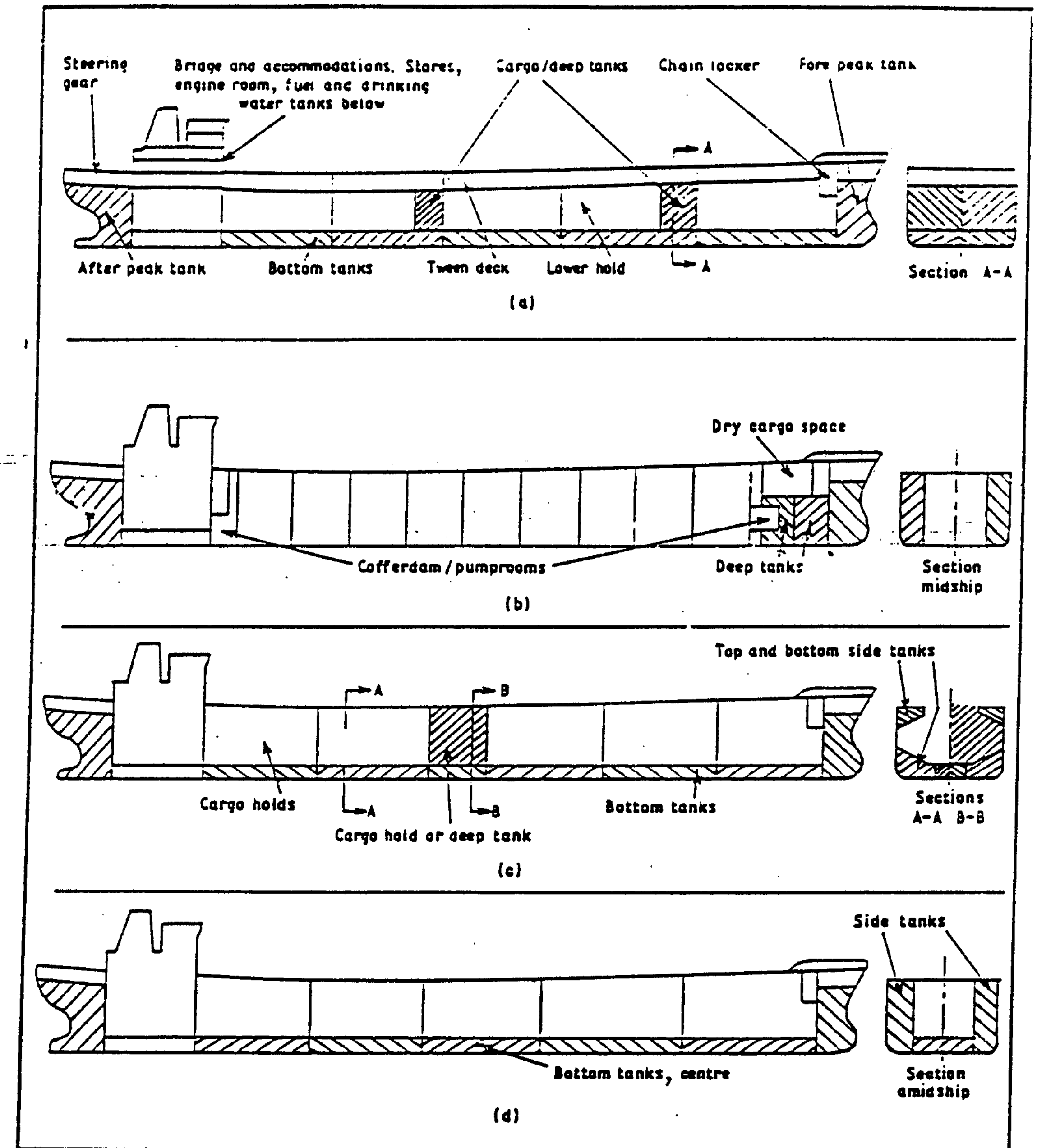


Fig I: Sketches show the same hull form used as a general cargo ship, oil tanker, bulk carrier and ore carrier. Hatched areas indicate ballast water spaces. Deck structures (forecastles, cargo hatches) are not shown. In the case of oil tankers, several ballasting schemes are acceptable, including segregated or dedicated cargo tanks that never carry cargo and cargo tanks that have been 'crude oil washed' (existing ships). In general, up to 30% of deadweight tonnage may be carried as ballast.

Figure 4-3

Structural Profile of a General Cargo Ship, Oil Tanker, Bulk Carrier, and Ore Carrier Emphasizing Ballasting Arrangements (from Schormann, Carlton, and Dochoda, 1990)

TABLE 4-3

LLOYD'S REGISTER'S (LR)*
SPECIFICATIONS OF BALLAST WATER (BW) CAPACITIES AND DISTRIBUTION IN SIX VESSEL TYPES

Units are in MT
Total BW capacity also shown (in parentheses) converted to U.S. gallons
[Tanks and holds in brackets: individual tank capacities not indicated in LR]

Vessel Type	Total BW Capacity	Tanks and Holds	Capacity
General Cargo Ship	4,200 (1,109,510)	Deep tank midship aft	890
		Deep tank midship forward	890
		Tunnel tanks	400
		Underdeck tank aft	20
		Underdeck tank forward	20
		[After peak tank, half-height deep tank, fore peak tank]	1980
Container Ship	2,400 (634,000)	Deep tank forward	300
		Side tanks (in No.1&2 holds)	1350
		[After peak tank, fore peak tank]	750
Bulk Carrier	18,000 (4,755,060)	Topside tanks in holds	6000
		Combined bottom and side tanks	8000
		[After peak tank, fore peak tanks, no. 4 hold or deep tank]	4000
Ore Carrier	10,000 (2,641,700)	[After peak tank, fore peak tank, bottom tanks, side tanks]	10000
Tanker	20,500 (5,415,480)	"Clean ballast tanks" [Side tanks]	14500
		[Half height] deep tank forward	3300
		[After peak tank, fore peak tank, cofferdam?]	2700
RoRo Cargo	350 (92,460)	Deep tank forward	90
		[Forepeak tank, other tanks]	260

* Lloyd's Register of Shipping (1991), London (three volumes)

TABLE 4-4

EXAMPLES OF BALLAST WATER CAPACITIES (BWCAP) IN NEWLY BUILT (1991) VESSELS OF A RANGE OF TYPES AND SIZES

Vessel Name	Type	DWT	BWCAP m3	BWCAP gallons
Annapurna	gas tanker	17562d	10077	2,662,000
Arbat	products tanker	39700d 45700s	18000	4,755,000
Bunga Kenari	container ship	21571d 23624s	7057	1,864,000
Bunga Siantan	palm oil tanker	16923sm	3268	863,000
CS Sovereign	cable ship	5060d 7454s	3380	893,000
Conger	chemical tanker	23400	7480	1,976,000
Dixie Monarch	woodchip carrier	44679	24616	6,503,000
Fandango	multirole tanker	46087d	21247	5,613,000
Ferry Lavender	longhaul ferry	2689d	6224	164,000
Front Driver	OBO	152001d 169178s	81354	21,491,000
Hakuryu Maru	steel coil transporter	2510d	2396	633,000
Halla No. 2	cement carrier	8050	2280	602,000
Hanjan Bangkok	feeder container	8075	3400	898,000
Hannover	container	55590d 67680s	16768	4,430,000
Helena	freight RoRo	11843d 12968s	6695	177,000
Helice	LPG	35600d 49500s	16140	4,264,000
Ishikari	pass/vehicle ferry	6146d 6938s	4723	1,248,000
Jo Alder	chemical tanker	12600	5000	1,321,000
Katarina	tanker	6000d 6330s	1706	451,000
Knock Allan	tanker	135000d 145000s	54000	14,265,000
Krasnograd	RoRo	14308d 17510s	4404	1,163,000
Landsort	tanker	141844d 163038s	57710	15,245,000
Olympic Serenity	tanker	96733d	35730	9,439,000
Society	expedition ship	1100d	624	165,000
Tycho Brahe	train ferry	2500	800	211,000
Western Bridge	bulk carrier	96725	44756	11,823,000
Yeoman Burn	bulk carrier	77500d/s	40726	10,759,000

DWT (deadweight tonnage): d, design; s, scantling; sm, summer

Source: Significant Ships of 1991 (Royal Institution of Naval Architects, London), 120 pp.

Persian Gulf could have 280,000 tons of ballast water (in ballast and in cargo tanks) -- or about 74,000,000 gallons of water. Typical ballast tank capacities in an Atlantic Class Vessel (ACV) container ship (built in the mid-1980s) and in a D9 (early 1980s) container ship are shown in Figures 4-4 and 4-5 respectively.

In general, vessels of various types carry ballast water proportional to their deadweight tonnage (DWT). A "universal estimate" of a typical proportion may have less value than (as used here) a vessel type-specific estimate. Schormann et al. (1990) stated that a vessel may carry "up to 30 percent" of its DWT as ballast (their Figure 1), or "between 25 and 35 percent DWT" (page 20-3). Jones (1991) calculated ballast capacity for bulkers and tankers as 60 percent DWT. Pollutech (1992) noted that ballast capacity may be 25 percent DWT on the average, 20 percent DWT for short voyages, and 30 percent DWT for heavy weather (with up to 40 percent DWT for "severe conditions"). They calculated ballast in general as 25 percent DWT. In the present study, ballast capacity was calculated for individual vessel types (general cargo, tankers, and bulkers) through the use of regressions based upon data gathered by NABISS/APHIS in the field. Ballast capacity data also appears in NABISS tonnage tables (Tables 4-9 to 4-12).

"In Ballast" versus "With Ballast" Vessels

Vessels are said to be *in ballast* when they have ballast water and no cargo aboard. A vessel is *with ballast* when cargo and some ballast water are aboard. Vessels on their "ballast leg" normally carry the most ballast water. Vessels on their "cargo leg" may also have ballast water, with amounts varying relative to the needs to provide stability for the vessel.

"No Ballast on Board": Unpumped and Unpumpable Ballast Water

Inbound vessels that have released their ballast water prior to or during cargo loading, and outbound vessels with full cargo loads, may have sufficiently little BOB that the mariner would report a ballasting condition of "No Ballast on Board" (**NOBOB**), even when very small amounts remain. Ballast may remain aboard a vessel because it is "unpumpable" (water trapped in tank or hold spaces such that the pump may lose suction and yet water remains in the vessel) or because pumping was not completed ("unpumped"). While the amounts of unpumped or unpumpable water, or of trim water in a loaded vessel, may be only in the hundreds or thousands of tons, from the point of view of a marine biologist these volumes of water (tens of thousands to hundreds of thousands of gallons) may still be of sufficient quantity to support an abundant and diverse assemblage of living organisms. It may be taken as a general rule that, with rare exception, virtually all vessels have some ballast water aboard all of the time.

Acknowledged, Unacknowledged, and Cryptic Ballast

U. S. Customs and port records do not normally record the amounts of ballast water carried when vessels are "in ballast", and usually do not record the presence of ballast water at all when vessels are "with ballast". We suggest in our Recommendations herein changes in how the U.S. Customs Bureau collects ballast and cargo condition data from arriving vessels that would permit capturing these data.

Because of the lack of federal reporting on ballast, we define the following categories of ballast, two of which overlap for conceptual purposes:

Ballast Compartment Capacities of an ACV Container Ship
(courtesy of Sea Land, Inc.)

Figure 4-4

COMPARTMENT CAPACITIES

TANKS	POSITION FRAMES	TOTAL WEIGHT (TONS)	LOADED WEIGHT (TONS)	L.C.G FROM M.S (M)	LONGL MOMENT (T-M)	V.C.G ABOV B.L (M)	VERT MOMENT (T-M)	T.C.G FROM C.L (M)	TRANS MOMENT (T-M)	VERT MOM OF F.S (T-M) BLACK	VERT MOM OF F.S (T-M) 98% FULL
WATER BALLAST TANK	(S G=1.025)	(100 %)									
FORE PEAK TANK (C)	202 - F.E	385.1		136.71	52647.	5.86	2257.	0.00	0	151	
AFT PEAK TANK (C)	A.E - 9	461.4		-135.75	-62635	11.36	5242.	0.00	0	3847	
NO 1 DEEP TANK (C)	193 - 202	869.6		124.45	108222.	5.60	4870	0.00	0	1574	
NO 1 D B TANK (P)	175 - 193	412.5		106.49	43906.	1.97	812	-2.86	-1179	817	
NO 1 D B TANK (S)	175 - 193	412.5		106.49	43906.	1.97	812	2.86	1179	817	
NO 2 D B TANK (P)	157 - 175	396.1		76.23	30195.	0.90	356	-7.20	-2852	2552	
NO 2 D B TANK (S)	157 - 175	396.1		76.23	30195.	0.90	356	7.20	2852	2552	
NO 3 D B TANK (P)	148 - 157	282.0		57.35	16173	0.87	245	-8.79	-2479	3475	
NO 3 D B TANK (S)	148 - 157	282.0		57.35	16173.	0.87	245.	8.79	2479	3475	
NO 4 D B TANK (P)	130 - 148	611.4		36.87	22542.	0.85	520	-9.24	-5649.	5568	
NO 4 D B TANK (S)	130 - 148	611.4		36.87	22542.	0.85	520.	9.24	5649.	5568	
NO 5 D B TANK (P)	121 - 130	303.8		16.33	4961.	0.85	258	-9.22	-2796.	2774	
NO 5 D B TANK (S)	121 - 130	303.8		16.33	4961.	0.85	258	9.22	2796.	2774	
NO 6 D B TANK (P)	103 - 121	607.4		-4.04	-2454.	0.85	516.	-9.23	-5606.	5566	
NO 6 D B TANK (S)	103 - 121	607.4		-4.04	-2454.	0.85	516.	9.23	5606.	5566	
NO 7 D B TANK (P)	85 - 103	607.5		-31.20	-18954.	0.85	516.	-9.22	-5601	5568	
NO 7 D B TANK (S)	85 - 103	607.5		-31.20	-18954.	0.85	516.	9.22	5601.	5568	
NO 8 D B TANK (P)	67 - 85	557.1		-57.81	-32206.	0.86	479.	-8.72	-4858	4816	
NO 8 D B TANK (S)	67 - 85	557.1		-57.81	-32206.	0.86	479.	8.72	4858	4816	
NO 9 D B TANK (P)	50 - 67	336.2		-83.33	-28016.	0.89	299.	-6.66	-2239.	1458	
NO 9 D B TANK (S)	50 - 67	336.2		-83.33	-28016.	0.89	299.	6.66	2239.	1458	
NO 2 WING TANK (P)	157 - 175	840.3		77.52	65140	6.29	5285.	-13.33	-11201.	489	
NO 2 WING TANK (S)	157 - 175	840.3		77.52	65140.	6.29	5285.	13.33	11201.	489	
NO 5 WING TANK (P)	121 - 130	369.4		16.32	6029.	6.88	2541.	-14.81	-5471.	19	
NO 5 WING TANK (S)	121 - 130	369.4		16.32	6029.	6.88	2541.	14.81	5471	19	
NO 7 WING TANK (P)	85 - 103	739.3		-31.21	-23074.	6.88	5086.	-14.81	-10949	40	
NO 7 WING TANK (S)	85 - 103	739.3		-31.21	-23074.	6.88	5086.	14.81	10949.	40	
NO 8 WING TANK (P)	67 - 85	711.7		-58.02	-41293.	7.02	4996.	-14.78	-10519.	40	
NO 8 WING TANK (S)	67 - 85	711.7		-58.02	-41293.	7.02	4996.	14.78	10519.	40	
NO 3 U W TANK (P)	148 - 157	194.2		57.49	11165.	14.78	2870	-14.81	-2876.	19	
NO 3 U W TANK (S)	148 - 157	194.2		57.49	11165.	14.78	2870.	14.81	2876.	19	
NO 4 U W TANK (P)	130 - 148	394.9		36.90	14572.	14.78	5837.	-14.81	-5848.	40	
NO 4 U W TANK (S)	130 - 148	394.9		36.90	14572.	14.78	5837.	14.81	5848.	40	
NO 5 U W TANK (P)	121 - 130	194.2		16.32	3169.	14.78	2870.	-14.81	-2876.	19	
NO 5 U W TANK (S)	121 - 130	194.2		16.32	3169.	14.78	2870.	14.81	2876.	19	
NO 6 U W TANK (P)	103 - 121	388.6		-4.06	-1578.	14.78	5744.	-14.81	-5755	40	
NO 6 U W TANK (S)	103 - 121	388.6		-4.06	-1578.	14.78	5744.	14.81	5755	40	
NO 7 U W TANK (P)	85 - 103	388.8		-31.22	-12138.	14.78	5746.	-14.81	-5758	40	
NO 7 U W TANK (S)	85 - 103	388.8		-31.22	-12138.	14.78	5746.	14.81	5758	40	
NO 8 U W TANK (P)	67 - 85	388.6		-58.37	-22683.	14.78	5744.	-14.81	-5755	40	
NO 8 U W TANK (S)	67 - 85	388.6		-58.37	-22683.	14.78	5744.	14.81	5755	40	
TOTAL		19162.8		8.85	169126.	5.94	113809.	-0.00	-0	72715	
FRESH WATER TANK	(S G=1.000)	(100 %)									
NO 1 F W TANK (S)	7 - 9	61.1		-131.35	-8025.	15.73	961	10.18	622	128	
NO 2 F W TANK (S)	5 - 7	63.6		-133.38	-8483.	15.73	1000.	9.86	627	145	
FEED WATER TK (P)	7 - 11	48.6		-125.94	-6121.	12.14	590	-8.05	-390	57	
TOTAL		173.3		-130.58	-22629.	14.72	2551	4.96	859	330	

Ballast Compartment Capacities of a D9 Container Ship
(courtesy of Sea Land, Inc.)

Figure 4-5

SALT WATER BALLAST TANKS — 35 Cub.ft./Long Ton

NAME	POSITION SIDE	POSITION FRAMES	CAPACITY Cub. m.	CAPACITY Cub. ft.	CAPACITY Long Tons	CENTER OF GRAVITY LCG (ft)	CENTER OF GRAVITY KG (ft)	FREE SURFACE SLACK (LT-ft)	FREE SURFACE 98%-5% (LT-ft)
Fore Peak Water Ballast Tank	---	264-F.E.	618.6	21,846	624.2	F 376.97	17.09	539	
No.1 Deep Water Ballast Tank	---	245-264	718.9	25,388	725.4	F 324.90	17.29	1849	
No.2 Deep Water Ballast Tank	---	227-245	383.1	13,529	386.5	F 280.31	8.33	2443	
No.1 Double Bottom W.B. Tank	P	191-227	279.2	9,860	281.7	F 204.20	5.09	2003	
No.1 Double Bottom W.B. Tank	S	191-227	279.5	9,670	282.0	F 204.17	5.09	2003	
No.3 Double Bottom W.B. Tank	C	119-N29	717.1	25,324	723.5	A 63.85	3.18	20584	
No.3 Double Bottom W.B. Tank	P	119-N29	672.6	23,753	678.7	A 63.58	6.69	4149	
No.3 Double Bottom W.B. Tank	S	119-N29	672.6	23,753	678.7	A 63.58	6.69	4149	
No.4 Double Bottom W.B. Tank	C	82-116	556.0	19,635	561.0	A 151.80	3.18	11934	
Aft Peak Water Ballast Tank	---	1-19	265.4	9,373	267.8	A 377.26	35.07	1643	
Total			5,163.0	182,331	5,209.5				

PERMANENT FRESH WATER TANKS — 36 Cub.ft./Long Ton

NAME	POSITION SIDE	POSITION FRAMES	CAPACITY Cub. m.	CAPACITY Cub. ft.	CAPACITY Long Tons	CENTER OF GRAVITY LCG (ft)	CENTER OF GRAVITY KG (ft)	FREE SURFACE SLACK (LT-ft)	FREE SURFACE 98%-5% (LT-ft)
No.2 Double Bottom W.B. Tank	C	N29-191	1,261.4	44,546	1,237.4	F 68.67	3.18	31491	
No.2 Double Bottom W.B. Tank	P	N29-191	981.2	34,651	962.5	F 60.89	6.73	7769	
No.2 Double Bottom W.B. Tank	S	N29-191	981.2	34,561	962.5	F 60.89	6.73	7769	
Total			3,223.8	113,848	3,162.4				

FRESH WATER TANKS — 36 Cub.ft./Long Ton

NAME	POSITION SIDE	POSITION FRAMES	CAPACITY Cub. m.	CAPACITY Cub. ft.	CAPACITY Long Tons	CENTER OF GRAVITY LCG (ft)	CENTER OF GRAVITY KG (ft)	FREE SURFACE SLACK (LT-ft)	FREE SURFACE 98%-5% (LT-ft)
Potable Water Tank	S	59-79	105.4	3,722	103.4	A 234.88	34.61	35	
Potable Water Tank	S	59-79	105.4	3,722	103.4	A 234.88	34.61	35	
Total (Potable Water)			210.8	7,444	206.3				
No.5 D.B. Feed Water Tank	P	62-81	124.0	4,379	121.6	A 225.69	5.71	761	
No.5 D.B. Feed Water Tank	S	54-68	43.9	1,550	43.1	A 253.28	5.77	110	
Total (Feed Water)			167.9	5,929	164.7				
Fresh Water Drain Tank	---	76-81	37.6	1,328	36.9	A 212.66	4.59	48	
Piston Cooling Fr.1. Tank	---	54-62	19.2	678	18.3	A 262.70	5.87	31	
Stern Tube Cooling Fr.1. Tk.	---	11-19	29.1	1,028	28.6	A 367.22	13.98	24	

OTHER TANKS — 36 Cub.ft./Long Ton

NAME	POSITION SIDE	POSITION FRAMES	CAPACITY Cub. m.	CAPACITY Cub. ft.	CAPACITY Long Tons	CENTER OF GRAVITY LCG (ft)	CENTER OF GRAVITY KG (ft)	FREE SURFACE SLACK (LT-ft)	FREE SURFACE 98%-5% (LT-ft)
Bilge Sep. Oil Tank	---	48-53	52.0	1,836	51.0	A 283.10	4.66	666	
Bilge Tank	---	34-48	120.5	4,255	118.2	A 304.46	4.43	775	

Acknowledged Ballast

Vessels in ballast as reported in official government records. The volumes of water actually aboard and the volumes of water to be discharged are never recorded. Vessels with *no cargo* are recorded as in ballast, regardless of actual ballast condition. Last port of call (**LPOC**) data are usually available, but LPOC is often not the specific source of the water on board (see discussion page 92).

Unacknowledged Ballast

Vessels with ballast water; these are not reported to or by government bureaus.

Cryptic Ballast

Unacknowledged ballast, unpumpable ballast, reported NOBOB when there is some minimal BOB, and ballast water on board vessels not recorded by government records. The latter are primarily military vessels. At this time we do not have a means to estimate the volume of foreign and domestic ballast water being transported by U. S. Navy military cargo and support vessels. We identify this inability as a potentially major gap in understanding the complete role of shipping in the potential introduction of nonindigenous species. An additional example is the semisubmersible exploratory drilling platform (SEDP), offshore drilling rigs which may transport not only ballast water but extensive fouling communities as well.

How Old is Ballast Water?

Prior to deballasting, ballast water can vary in "age" (length of time resident in the tank or hold) from < 24 hours to many months. Container ships and RoRos travelling between coastal ports will take up and deballast water at different ports in less than one day. At the other extreme, vessels may take on "permanent" or "semi-permanent" water ballast, especially in double bottom and peak tanks, which may have a tank residency of many months before being changed. Little is known about the physical, chemical, or biological qualities of this "old" water. Williams et al. (1988) suggested that "few, if any, animals are likely to be present after a transit time of about 24 days" in bulk cargo vessels arriving in Australia from Japan. Carlton (1985) noted the presence of a diverse array of living organisms in ballast water 31 days old, and found copepods in water 95 days old. Whether these latter organisms (a) were the original animals ballasted three months earlier, (b) were second or third generation animals descended from the original animals or (c) (as suggested by Williams et al., 1988) were released from encysted stages, is not known. Nonetheless, it does suggest that as long as the chemical and physical environment in a tank does not degrade below the ability to support life, "old" ballast water may contain living organisms. It may be noted that virtually nothing is known of the biological status of even "long haul" water (such as water from Australasia arriving on the U.S. East Coast).

Ballast Water and Sediment as a Habitat and Transport Mechanism for Living Organisms

Carlton (1985, p. 315) has characterized the physical-chemical environment in a ballasted tank or hold as follows;

"There is no light. Tank temperatures may either remain close to the original temperature of the ballasted water or, more commonly, mirror (with some lag time), within one or two degrees, the water or air temperature the vessel is in or

passing through. Such variations depend upon the position and size of the ballast tank. Oxygen content may vary considerably, depending upon initial concentration, the amount of air space remaining in the tank after it is filled (the ullage, or the height of the space above the water surface), the size of the tank, and the nature of the tank walls (for example, whether heavily rusted or not)... Other variables dependent upon the location and time of ballasting may include water quality (extent of organic or inorganic pollutants), salinity, pH, and sediment load. Some of these (such as salinity) may remain stable during a given voyage, while others (such as temperature and oxygen) may change considerably."

There may also be additional in situ sources of contamination (from metals, grease, oil, old cargo) aboard the ship, although these are rare, and usually are caused by minor leaks or by accident. More serious is ballast tank corrosion (Anonymous, 1992a). Corrosion induced by sulphate-reducing bacteria, taken up with high sediment loads in harbor waters, can produce extensive ballast tank corrosion in the form of severe localized pitting (Anonymous, 1992b). In turn, high concentrations of sulphate-reducing bacteria produce aggressive metabolites, destroy corrosion resistant additives, depolarize cathodic processes, and create changes in the concentration of oxygen; the bacteria are anaerobic and given the right conditions will form sulphides (Anonymous, 1992b).

While tanks and holds in vessels may at times not support any living organisms, such events are rare, and almost all vessels ever sampled in Canadian, Australian, and U.S. studies to date have been found to contain living organisms (Bio-Environmental Services, Inc., 1981; Jones, 1991; Hallegraeff and Bolch, 1992; Carlton and Geller, 1993). There is now no question that ballast water provides a viable in-transit habitat for a wide variety of freshwater, brackish water, and marine organisms. We estimate that more than 500 different species of animals (zooplankton and benthos) and "plants" (dinoflagellates and algae) have been found in U.S., Australian, and Canadian studies. NABISS interviews with ships' officers and crews revealed a number of incidences when (for example) "little fish, one inch long," a "school of crabs," and "millions of shrimp" were observed in ballast tanks.

Figure 4-6 presents the hypothetical sequences of events that take place during the uptake, transportation, and release of aquatic organisms by ballast water (Carlton, 1985). This sequence provides a framework for biological investigations. From the surrounding waters at any given location a subset of species is drawn into the vessel (Stage I), depending upon the time of ballasting (a broad suite of different organisms are typically in the water column at night, arising from bottom sediments as nocturnal vertical migrators), the tidal state (ebbing tides bringing organisms from up-river sources, flood tides bringing organisms from down-river sources), the depth of ballasting (many species are vertically stratified in the water column, and thus would or would not be ballasted depending upon the depth of the intake), and so forth. Vessels which have remained in port for a number of hours or days may also have their intake grates and openings temporarily colonized by local species which, when the ballast pumps are activated, may be suddenly drawn into the vessel (an excellent example of this phenomenon (Carlton, 1985, p. 356) is the propensity of crevicolous (hole-seeking and hole-dwelling) fish, such as gobies, to be transported by ballast water around the world, a phenomenon linked to these fish entering the ballast intake covers while the vessel is tied up at the dock).

The potential diversity of "ballastable biota" is often not fully appreciated. Virtually all aquatic organisms that can occur in the water column, actively or passively, or be stirred up from bottom sediments, or rubbed off harbor pilings, could be ballasted into a vessel. We review this

Hypothetical Sequence of Events in the Dispersal and Introduction of Non-Indigenous Species by Ballast Water (from Carlton, 1985)

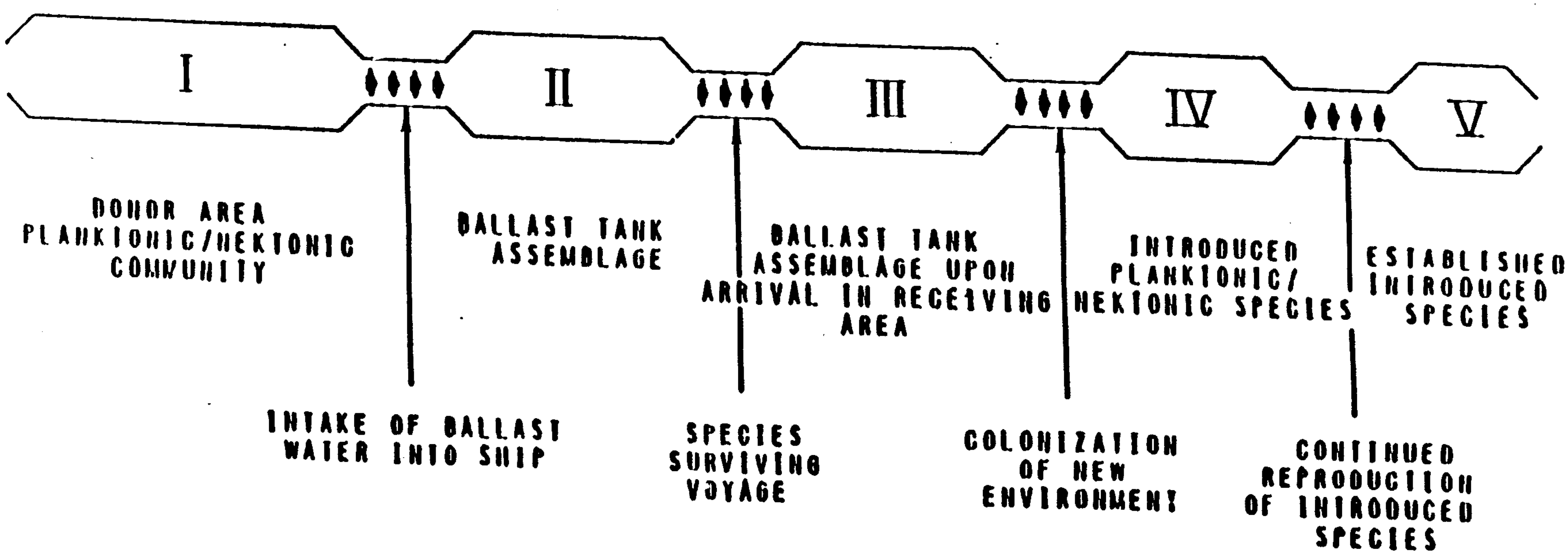


Figure 4-6

background biota in Box 4-4.

Biological data for Stage I - II are limited. Studies in 1981-82 (Carlton and Navarret, unpublished) with the R/V Knorr at the Woods Hole Oceanographic Institution (WHOI), comparing shipside plankton to plankton in ballast tanks immediately after ballasting revealed that (a) not all species in external plankton tows (to the depth of the vessel's intake) re-appeared in the ballast tanks and (b) some species occurred in the ballast tank that were not collected in shipside plankton tows. An alternate explanation for (b) is that there were residual organisms left over from earlier ballast water (although in this particular case this was not likely, given the Knorr's history of ballasting). These results underscore the patchy nature of plankton populations, and indicate that thorough species lists of the plankton at a site would be required to understand the full range of ballastable biota.

The eventual ballast biota (Stage II) is then transported from Point A to Point B. We discuss natural mortalities at this stage in Box 6-4 in the control options section. Those species arriving alive (Stage III) are then released, although since most vessels do not or cannot deballast all of their water, some of the organisms from Point A remain aboard, hypothetically to be deballasted elsewhere in the ship's voyage, or mixed with "new" ballast from Point B. The released organisms are thus *inoculated* into the environment; if reproduction is successful, certain species may become established.

Data for Stage II - III are similarly limited. Four studies are or will be available:

(1) Studies in 1981-2 (Carlton and Navarret, unpublished) with the R/V Knorr at WHOI quantified in detail the differences in diversity and abundance of holoplankton and meroplankton in the Knorr's ballast tanks at the beginning and at the end of cruises of different durations. Post-transport survival was high with differential mortality and/or survival (and reproduction and metamorphosis) experienced by different taxa; these results provided the initial impetus for continuing ballast studies at WHOI and later at the University of Oregon.

(2) Studies aboard the R/V Knorr on a voyage from Scotland to Iceland to Newfoundland to Massachusetts (Carlton, 1985), again with differential survival among different taxa.

(3) Studies aboard the M/V Martha Ingram, on a voyage from cold northern waters (New Hampshire) to warm southern waters (Gulf of Mexico) (Carlton, 1985), documenting the survival of a number of cold-water species well after the ballast water had risen to ambient sea temperatures.

(4) Studies completed by G. Hallegraeff and G. Rigby in a trans-Pacific voyage aboard a bulk carrier from Japan to British Columbia (G. Rigby, personal communication, 1992, and Hallegraeff and Rigby, in preparation), demonstrating the effect of varying the extent of ballast exchange on the presence of residual organisms from the original ballasting site.

All of these studies indicate that there is differential survival between stages II and III, but that the remaining biota at Stage III can be abundant and diverse.

Most available studies focus on Stage III, the ballast tank biotic assemblage upon arrival in the port of call. The discovery of living organisms in ballast water and sediments was announced

BOX 4-4

THE RANGE OF ORGANISMS THAT COULD POSSIBLY BE BALLASTED INTO A VESSEL

Virtually all planktonic and suspended aquatic organisms that can occur in the water column could be ballasted into a vessel. Outlined below are the categories of "ballastable biota." We include here **viruses, bacteria, protists (including "protozoans"), fungi and molds, and plants and animals**. It is important to note that the **parasites, pathogens, and symbionts** of all of these organisms can of course also be transported.

Holoplanktonic Organisms

Those organisms that spend most or all of their life cycle in the water. In coastal and open ocean marine systems these include ***PHYTOPLANKTON (diatoms, dinoflagellates, blue-green algae, nannoplankton, autotrophic picoplankton, and other groups) and ZOOPLANKTON (comb jellies, jellyfish, hydrozoans (siphonophores), polychaete worms, rotifers, gastrotrichs, planktonic gastropods (snails: the pteropods and heteropods), copepods, hyperiid amphipods, isopods, mysids, ostracods, cladocerans, pelagic shrimps, krill (euphausiids), arrow worms (chaetognaths), pelagic tunicates (including salps, doliolids, and larvaceans)), and FISH.***

Neustonic organisms, those that occur at or near the air:sea interface, are potentially ballastable if carried by turbulence or local downwelling to the depths of the ballast intakes (a presumably rare event). Such organisms include larvae and juveniles of ***the by-the-wind-sailor Velella, the blue button Porpita, nauplii and cyprids of the barnacle Lepas, and the sea strider Halobates.***

> While the global focus on ballast water has been on the transoceanic or interoceanic movement of coastal (neritic), shallow-water organisms, an often overlooked, but potentially critical, role of ballast is the movement of open ocean species between ocean basins. Vessels frequently ballast and/or exchange their water along their shipping routes. High seas, oceanic organisms such as ***radiolarians, silicoflagellates, globigerinid foraminiferans, copepods, and chaetognaths,*** otherwise restricted by major oceanic gyres and temperature boundaries (such as the tropical barrier between the northern and southern hemispheres) could easily be transported and released between ocean basins. Ballast water has not been examined as a potential explanation for the at times unusual disjunct populations of certain groups in the Pacific and Atlantic Oceans.

Meroplanktonic Organisms

Those organisms that spend a portion (usually the shorter) of their life cycle in the water column. In coastal and open ocean marine systems these include ***PHYTOPLANKTON (the dispersal propagules of benthic plants) and ZOOPLANKTON (the larvae of many benthic invertebrates, including sponges, sea anemones, corals, hydroids, mollusks (snails (including seaslugs, or nudibranchs), chitons, and mussels, clams, oysters, and scallops), crustaceans (barnacles, shrimp, lobsters, crabs, hermit crabs), nemerteans (ribbon worms), sipunculans, polychaete worms, bryozoans, phoronids, echinoderms (seastars, brittle stars, sea urchins, sea cucumbers), hemichordates, tunicates (sea squirts)), and the larvae of fish.***

As with oceanic holoplankton, ***oceanic teleplanic (long-distancing dispersing) meroplankton (larvae)*** are susceptible to transport by ballast between oceans and ocean basins.

BOX 4-4 (continued)

THE RANGE OF ORGANISMS THAT COULD POSSIBLY BE BALLASTED INTO A VESSEL

Demersal Organisms

Those organisms that migrate vertically up into the water column at night. Many shallow-water organisms rise up off the bottom and become common in the water at night. These organisms include a variety of small ***crustaceans (including gammarid amphipods, isopods, mysids, cumaceans, crangonid and other shrimp, and benthic harpacticoid copepods), some fish species, and polychaete worms.*** The presence of such organisms in abundance in the ballast water may mean that the vessel ballasted at least a portion of its water during the night. Carlton et al. (1993) note that by returning at night to sample the cargo hold of a bulk carrier, demersal organisms rising from the bottom of the tank (through a > 15 meter water column) can be found.

Tychoplanktonic Organisms

Those bottom organisms that get swept up into the water column (by tidal currents, waves, ships' propellers) and remain buoyant in the water for varying lengths of time. Examples include ***forams, flatworms, polychaetes, crustaceans (copepods, amphipods, isopods, and tanaids), hydroids, benthic copepods, insect larvae, mites, and nematodes.***

Benthic Organisms in Sediments

Those organisms that could be brought into a vessel with bottom sediments include ***all of the benthic groups listed above, as well as leeches, oligochaete worms and insect larvae and adults.***

Floating, Detached Biota

A broad suite of floating, detached organisms can be drawn into a ship, including ***seaweeds (algae), seagrasses (eelgrass, Sargassum, turtle grass), and marsh plants***, as well as the **epiphytic organisms on the blades of floating plants, such as *spirorbid tubeworms, bryozoans, seasquirts, and sponges, mollusks, and crustaceans.***

"Migratory" Organisms

"Migratory" organisms include such unusual animals as the wood-boring gribble <u>Limnoria</u>, a tiny isopod crustacean which undergo nocturnal excursions known as migrations by swimming between wood habitats (and for which ballast dispersal -- in the form of the uptake of small pieces of gribble-infested wood -- has been proposed; reviewed in Carlton (1985)).

Fish and Shellfish Diseases, Pathogens, and Parasites

As Hutchings (1992) has noted, marine diseases, pathogens, and parasites, including well-known mariculture and aquaculture diseases, are potentially transportable by ballast water.

by Australian scientists in 1975 (Medcof, 1975), followed by more extensive studies published in 1988 (Williams et al. 1988). Elegant work has continued on this phenomenon in Australia (Hallegraeff et al., 1990, Hallegraeff and Bolch, 1991, Jones, 1991, Hallegraeff and Bolch, 1992, Hallegraeff, 1992, Hutchings, 1992). Canadian (Bio-Environmental Services, Ltd., 1981 (see Carlton, 1992, p. 697, for comments on this study), Locke et al., 1992a, b, Locke et al., 1993) and United States (Carlton, 1985, Kelly, 1992a, 1992b, Carlton and Geller, 1993) studies provide further extensive lists of the animals and plants that have been found alive in post-transit ballast water and sediment samples. Bacteria and viruses have also been found in ballast tank samples (Bio-Environmental Services, Ltd., 1981, Adess, 1982, USCG/CDC/FDA, 1991, Hallegraeff and Bolch, 1992, p. 1082, Jones and Caughley, 1992). All major phyla of marine organisms have now been found in ballast water and sediments. The total number of species from all of these studies now exceeds 500, a number that may well correspond to the number of species *in transit* in thousands of vessels around the world *on any one day.*

The release of species into the environment (Stage III to Stage IV) leads to differential survival of the species involved. The greater the temperature differences between donor (source) and receiver (target) regions the greater the probability of high mortalities. Thus most organisms from tropical ports will not survive or reproduce in temperate or boreal ports, and vice-versa. Exceptions occur where tropical and subtropical species are transported to and establish reproducing populations in power plants thermal effluents, a phenomenon well-known in Europe and North America (Carlton (1992b) reviews examples among mollusks for Atlantic North America).

As discussed in Chapter 5, many other variables in addition to temperature mediate the potential survival of newly-released organisms. Thus even when and where temperatures are similar between the ballast water and receiving waters, salinity, oxygen, light, food, and many other factors may be inhospitable or limiting.

A very small number, perhaps less than three percent, of all species released by most transport mechanisms (including ballast water) actually become established in new regions (Stage V). As demonstrated by the zebra mussel and many other important invaders, however, the *number of introduced species* is not related to their environmental or societal impacts. Only one successful invader is required to dramatically alter the environment.

Attached Fouling Organisms in Ballast Tanks

Fouling organisms on the inside of ballast tanks appear to be rare, or are rarely reported. Newly settled barnacles and hydroids have been observed at the waterline of ballasted cargo holds in bulk woodchip carriers arriving at the end of a two week voyage from Japan to Coos Bay, Oregon (Carlton et al., 1993). These organisms had been taken aboard as larvae, settled out, and grown during the voyage. Emptying of the tank to load cargo leads to the complete mortality of these fouling organisms. Bio-Environmental Services Ltd. (1981, volume I, page 7) reported "encrustations" on the walls of a ballast tank, but this appears to have been in error (Carlton, unpublished).

Ballast Sediments

Suspended materials may be taken aboard into ballast systems with water from any location. These materials may then settle in ballasted cargo holds and in ballast tanks. In cargo

holds such materials may be combined with residual cargo, such as woodchip fibers and fragments, to form a combined bottom layer (a "sludge") of chips and sediment. In ballast tanks sediments may accumulate as a mud layer (perhaps mixed with rust and other tank wall derivatives). Muddy accumulations in ballast tanks are rarely in excess of four inches in depth in a two to four year period (J. Schormann in Adess, 1982, p. 10). Canadian workers report (IMO/MEPC, 30th Session, Agenda Item 15, page 15, item 5.3.5.4) that "vessels whose tanks have been treated with non-toxic epoxy coatings are less likely to retain sediment."

Williams et al. (1988) report analyzing "mud, shovelled from the bottom of drained ballast tanks into buckets" in Japanese vessels arriving in Australian ports. This mud was examined for the presence of macrobenthic animals. Sediment volumes examined ranged from between five and 30 liters per vessel. Polychaete worms and crustaceans occurred in these samples, including a wide variety of amphipods, shrimps, and crabs.

Hallegraeff and Bolch (1991) report that of 200 cargo ship ballast tanks sampled by Australian Quarantine and Inspection Service (AQIS) officers between 1987 and 1989, over 70 percent "had sediments on the bottom of their ballast holds". Thirty-one of 83 of the samples examined contained viable dinoflagellate cysts. One ship was estimated to contain more than 300 million cysts of the toxic dinoflagellate *Alexandrium*. By 1990 a total of 343 cargo vessels had been sampled from 18 Australian ports (Hallegraeff and Bolch, 1992). Of these, 65 percent "were carrying significant amounts of sediment on the bottom of their ballast tanks," although some of the remaining samples were sediment free because tank bottoms were inaccessible. These sediments consisted of "fine brown or black sediment" with "an estimated 100 tonnes of sediment per ship." In these studies "ballast tanks" refer to both true ballast tanks and to ballasted cargo holds (Hallegraeff and Bolch, 1992, p. 1068). Dinoflagellate cysts (resting spores) were present in 50 of the 100 sediment samples examined and five contained toxic dinoflagellate species. Diatoms were also common. Samples from the cargo holds were more likely to contain a high proportion of live cysts than double-bottom, wing, or topside ballast tanks (Hallegraeff and Bolch, 1992, p.1072).

Kelly (1992a, b) found that bulk cargo woodchip ships interviewed in the State of Washington disposed of collected sediments overboard once the ship departed local port waters, but that "the collection of sediments for all ships involved a cleaning procedure that occurred when the ship was at dock or anchor, and resulted in the discharge of sediments directly into port waters." Williams et al. (1988) had similarly earlier reported that sediments were dumped overboard in ports in large quantities. We discuss NABISS findings on sediment management in ballast tanks below, and sediment disposal and control alternatives at option 23.

(B) BALLAST WATER: OPERATIONS, HOW MUCH, AND WHERE FROM

Ninety-seven vessels of 12 different types of vessels were boarded in 21 ports (these are combined as 17 port systems in Table 4-5). Most frequent were container ships and bulkers, followed by tankers. The geographic distribution of vessel boardings was as follows: East coast: 26, Gulf coast: 22, Pacific coast: 40, Alaskan coast: 3, Hawaiian coast: 6. In addition, as noted in Chapter 2, a cooperative program with USDA/APHIS provided us detailed information for more than 1000 vessels. Also as previously discussed, we analyzed in detail selected data sets on vessel arrivals available through Customs-Census data gathering and synthesis. Taken together, these data provided us with an extensive and detailed picture of ballast practices and knowledge in the United States.

NABISS VESSELS: BALLAST OPERATIONS

Records of Ballast Water Operations (BOPS) Aboard Vessels

"Ballast Water Operations" (or BOPS) means the entire process of why, when, where, and how water is brought into or taken out of a vessel. We determined what records are typically kept aboard vessels (a single vessel may have more than one means of recording these data):

(1) Only 6 vessels (7 percent) stated that they kept no BOPS records at all.

(2) 24 vessels (25 percent) kept some type of record *on computer.* These data were normally retained for relatively long periods.

(3) 46 vessels (48 percent) kept some type of record *in the ship's log.* These records could include dates and times pumps were started and stopped, tanks ballasted or deballasted and noon position (latitude x longitude) for the days when BOPS were conducted and recorded.

(4) 20 vessels (21 percent) kept some type of *specific ballast log.*

(5) 57 vessels recorded BOPS in the following (total 86 records: a single vessel may have more than one additional record): oil pollution record/book, 5; bell book, 1; officer's personal log/book (captain, quartermaster, first/chief mate/officer/engineer, carpenter), 18; condition report (arrival and departure at each port), 19; sounding log/book (daily or weekly), 15; engine room log/book, 4; ballast water report form, 1; deck log or duty book, 6; port log/book, 2; load/cargo log or stability calculation record, 15.

Reasons for Conducting Routine BOPS (including Ballast Water Exchange)

Ships' officers were asked to advise us on (a) normal operations when fuelling, (b) normal operations in adjusting for trim or list while docked, and (c) normal operations when arriving or departing a port.

(A) Normal Operations When Fuelling

Ninety-five vessels responded to this question; 85 (89 percent) vessels normally did not

TABLE 4-5

NABISS PORT VISITS: TYPES AND NUMBERS OF VESSELS BOARDED BY PORT

PORT	VESSEL TYPE*										
	Cont	C/GC	GeCa	Bulk	OBO	Tank	ChTk	RoRo	Car	Reef	LASH	CR
Norfolk	3			1								
Baltimore				2	1				2			
Charleston	2					2						
Savannah	2			3								
Tampa				2						1		
Miami				1				2				2
New Orleans			1	3		4					1	
Galveston	1		2	1			1					
Houston			1	2			2					
Boston				1		1				1		
LA/LB	3			3		1	1	1	2	2		2
San Diego				1								
Honolulu	4			1		1						
SF/Oakland	5	1										
Portland				3					1			
Seattle/Tacoma	10			4								
Anchorage	1			1				1				
TOTAL	31	1	4	29	1	9	4	4	5	4	1	4

* Vessel Type Codes:

Cont	Container
C/GC	Container/General Cargo
GeCa	General Cargo
Bulk	Bulk Carrier (Bulker)
OBO	Ore/Bulk/Oil
Tank	Tanker (usually petroleum)
ChTk	Chemical Tanker
RoRo	Roll-On Roll-Off (vehicles, trailored cargo)
Car	Car Carrier (specific)
Reef	Reefer (refrigerated vessel, usually for perishable food)
LASH	Lighter-Aboard-SHip (barge-carrying vessel)
CR	Cruise (Passenger) Ship

have to adjust their ballast condition as a result of fuelling (bunkering, taking on bunkers, etc.). Five vessels reported that they regularly discharged BW while fuelling (apparently to compensate for the weight taken on), 3 additional vessels also reported that they regularly discharged BW while fuelling (here apparently to maintain trim), and 2 vessels reported that sometimes they took on BW, and sometimes they discharged BW, when fuelling.

(B) Normal Operations in Adjusting for Trim or List While Docked

Ninety-five vessels responded to this question; 6 (6 percent) vessels indicated that they did not normally conduct BOPS at the dock. However, 45 vessels (47 percent) reported that to maintain trim and list (minimize list) when handling cargo alongside the dock, they normally took on or discharged BW as required; 26 vessels (27 percent) reported that they normally shifted onboard BW as required, and 18 vessels (19 percent) reported that they conducted whatever BOPS seemed necessary at the time (took on, discharged, or shifted).

(C) Normal Operations While Arriving or Departing a Port

Ninety-five vessels responded to this question; 16 vessels (17 percent) had no preference as to whether they conducted BOPS in or out of port. Thirty-seven vessels reported that they preferred to take on ballast water while in the port (probably to assure stability before departure), while 42 vessels (44 percent) reported that they preferred to take on ballast water outside of the port (usually related to taking on "dirty" BW). "Preference" was, of course, subjective -- an officer would not "prefer" to take on BW outside of the port if his vessel would have been unstable to get there; answers were predicated on the assumption that the officer had some choice as to where BW was taken on.

BOPS By Vessel Types:

Container Ship

All 31 container ships responded that they were capable of "completely" exchanging their ballast. One vessel noted that this was dependent upon stability, and another noted that it would not include 3400 MT of freshwater (permanent) ballast water in an exchange. Relative to fuelling operations, 2 vessels (7 percent) normally discharged, and 2 vessels (7 percent) normally took on ballast as a consequence of fuelling, and 1 vessel (3 percent) normally took on or discharged ballast as required. The remaining 26 vessels (84 percent) did not normally have to adjust their ballast as a consequence of fuelling. Relative to dock-side adjustments, 30 (97 percent) vessels normally conducted some kind of BOPS while at the dock, while 1 vessel (3 percent) did not. Five vessels (16 percent) normally took on or discharged ballast at the dock, 17 vessels (55 percent) normally shifted onboard ballast while at the dock, and 8 vessels (26 percent) normally took on, discharged or moved ballast as required while at the dock. Relative to arrival/departure, 10 vessels (32 percent) preferred to conduct their BOPS in port, 17 vessels (55 percent) preferred to conduct their BOPS outside the port, and 3 vessels (10 percent) had no preference.

Bulkers

Twenty-nine (97 percent) of the 30 bulk ships responded that they were capable of "completely" exchanging their ballast. One vessel (3 percent) reported that it could not exchange 14,000 MT of ballast in its wing tanks. Relative to fuel operations, 1 vessel (3 percent) normally

took on or discharged ballast as required as a consequence of fuelling. The remaining 28 vessels did not normally have to adjust their ballast as a consequence of fuelling. For trim or list at the dock, all 30 vessels normally conducted some kind of BOPS while at the dock, taking on or discharging ballast, while only 2 vessels (7 percent) normally moved onboard ballast between tanks while at the dock. For port arrivals/departure, 14 vessels (47 percent) preferred to conduct their BOPS in port, 9 vessels (30 percent) preferred to conduct their BOPS outside the port, while the remaining 7 vessels (23 percent) had no preference. Due to the nature of a bulk ship's cargo, and to the quantities of ballast moved as a consequence of regular cargo handling, most of the "normal" ballast tanks would be handled (filled) while at the dock.

Tankers

Thirteen ships reported that they were capable of "completely" exchanging their ballast. Regarding fuelling operations, 2 (15 percent) vessels normally discharged, and 1 vessel (8 percent) normally took on ballast as a consequence of fuelling. The remaining 10 vessels (77 percent) did not normally have to adjust their ballast as a consequence of fuelling. Relative to dockside operations, all vessels normally conducted some kind of BOPS while at the dock: 6 vessels (46 percent) normally took on or discharged ballast at the dock, 3 vessels (23 percent) normally shifted onboard ballast while at the dock, and the remaining 4 vessels (31 percent) normally took on, discharged or shifted ballast as required while at the dock. Six vessels (46 percent) preferred to conduct their BOPS in port, 3 vessels (23 percent) preferred to conduct their BOPS outside the port, and 4 vessels (31 percent) had no preference.

Description of the General Relationship between BOPS and Cargo Carried

Container Ships

Container ships can carry thousands of containers and stop at dozens of ports on regular round-the-world trade routes or on a regular run between a few ports. As discussed earlier, as the vessel loads and/or unloads at any given port, the distribution of cargo on board constantly changes, resulting in changes in the vessel's trim and list. Trim and list are compensated for by adjusting the cargo, taking on or discharging ballast, or shifting onboard ballast. A container ship often carries ballast from many different ports (Table 4-2), usually homogenized to some extent in the various ballast tanks. Our APHIS survey indicates that while in port, container ships discharge and take on 300 to 400 MT of ballast water on average in each port.

Bulkers

Bulk carriers may be on standard repetitive trade routes, such as many of the west coast woodchip carriers going back and forth between Japan and California (Sacramento), Oregon (Coos Bay), and Washington (Port Angeles and Tacoma), or they may carry a different cargo to a different port on each trip.

These ships often carry a single bulk commodity such as coal, ore, woodchips, sugar, wheat, or scrap metal. These commodities may be loaded in total at one port and unloaded in total at the next port. By necessity the bulker has to arrive at the loading dock in ballast, discharge its ballast while loading is underway, and depart in partial or full cargo. Also by necessity, the bulker generally arrives at the unloading dock in full cargo, takes on ballast while the cargo is unloaded, and departs the dock in ballast. Bulkers may also pick up partial loads of cargo (scrap iron and woodchips are common examples) at a number of sequential ports before

offloading the entire cargo at one final destination port.

This is a common, though not universal situation. Bulkers often carry mixed bulk commodities, break bulk, general cargos or containers that may be loaded and unloaded at different ports. In these cases, the bulker's BOPS are dictated by the cargo carried, and the bulker "acts" like break bulk, general cargo or container carriers with respect to its BOPS. The opposite is also true: a break bulk or general cargo ship carrying a single-commodity load of coffee beans will "act" like a bulker with respect to its BOPS. It would have to have arrived in ballast at its loading port, will travel with little or no ballast while carrying a full load of cargo, and will be in ballast again after discharging its cargo at the destination port.

Tankers

In general, tankers behave very similarly to bulk carriers as far as BOPS are concerned. Again, they may be fully loaded with a single commodity as in a VLCC, while chemical tankers may carry a different chemical in each hold, such chemicals having been taken on board and being bound for many different ports. The cargo carried dictates, to a large degree, the vessel's BOPS.

Other Vessel Types

BOPS of general cargo carriers, reefers, and RoRos are also determined by the cargo carried. Single-commodity cargoes with single loading and unloading ports usually dictate BOPS similar to those of a bulker or crude carrier, while multiple-commodity cargos or trade routes involving multiple ports dictate BOPS similar to a container carrier. The complete spectrum between the two extremes can be found.

Ballast Water Exchange: Overall Patterns

Ninety-four vessels (98 percent) reported that they were capable of undergoing a "complete" exchange of BW at sea. Of the 2 vessels that could not, one was incapable of exchanging 14,000 MT of BW. This capability was dependent upon good weather conditions at the time of exchange and the stability of the ship (whether or not the ship would retain enough stability during exchange). Twenty-seven vessels (28 percent) reported that they had exchanged their ballast water at some time in the past. In at least 5 vessels this was a partial exchange, and in 5 others the ballast tanks were flushed by flow-through exchange. In one additional case, a vessel conducted a complete exchange and then additionally flushed her tanks.

Eleven vessels exchanged their BW because it was required or perceived to be required by their country of destination (Canada 1, Australia/New Zealand 7, China 1, Brazil 1, USA 1 (the latter because the captain was unsure if there were regulations or not). Eleven vessels exchanged their BW to get rid of "dirty" water. Four vessels exchanged their ballast water to get rid of cold water; this was usually done to avoid condensation in adjacent holds, although one vessel reported that the cold water was causing the fuel in adjacent fuel tanks to thicken. One vessel exchanged the fresh water in its ballast tanks so the water would not freeze on a trip to Alaska.

Maintenance Operations: Ballast Tanks

The following data pertain to routine maintenance schedules, not to situations where an inspection or some type of maintenance is conducted in response to a specific problem or occurrence. Overall, dry-dock interval was recorded for 76 vessels. This interval ranged from 1 to

5 years, averaging 2.3 years (about 2 years and 4 months).

Forty-three vessels (45 percent) reported that at least some of the BW tanks were inspected on a regular basis (that is, more often than during dry-docking), as follows:

21	BW tanks inspected more than once/year
16	BW tanks inspected once/year
2	BW tanks inspected every 2 years
3	BW tanks inspected whenever the ship is fully loaded with cargo (that is, the BW tanks should be empty)
1	topside tanks of a bulker were inspected each time before they were loaded with cargo
1	BW tanks inspected every 5 years (every second dry-docking)
1	BW tanks inspected every 5 years (every second or third dry-docking)

Eighty-six vessels were asked if they had ever specifically had a "problem" (defined as a maintenance or management problem) with sediment in their BW tanks. Sixteen vessels (19 percent) reported that they had a sediment problem at some time. Thirteen vessels (15 percent) reported sediment problems regularly or occasionally, with sediment having to be removed in dry dock or by being "hosed out" as required. Amounts were reported as **depths** ("50 cm of mud flushed with hoses") or **volumes** ("5 barrels of sediments two months ago") or as **weights** (four MT removed at the last dry-docking, or 2.5 MT of sediments removed before the last dry-docking). One vessel had its tanks commercially cleaned every four to five years; another reported that sediment was cleaned out every five years. One vessel recalled sediment problems once in the forepeak tank.

Several officers reported that if possible they avoided certain harbors, ports, or general regions that they believed had high sediment loads. These sites included for example the Mississippi River, Cook's Inlet (Alaska), Anchorage, and Montreal.

Maintenance Operations: Anchor Systems

Ninety-six vessels (100 percent) reported that they had a washing system in their hawse-pipes to wash the anchor chain as it was taken on board after use. In some cases, the nozzles were reported as damaged or the system was otherwise not working entirely as designed. Twenty-eight (35 percent) out of 81 vessels asked reported that they had some type of regular inspection schedule of their chain lockers as follows: more than once/year (21), once/year (6), sounded daily (1), sounded every few days (1), inspected after heavy seas (1), after muddy ports (1), and every trip (1). One vessel reported inspections only once every two years (with dry docking every five years).

Forty-one vessels (43 percent) reported that the chain lockers were only inspected during dry-docking. Three vessels reported that the chain lockers were inspected at every second dry-docking (one, every 2 years (dry-docking annually); one, every 3 years (dry-docking every 1.5 years), and one, every 5 years (dry-docking every 2.5 years)).

Awareness of Ship's Officers of Ballast Water Transport of Living Organisms

In the following, multiple answers were possible (and thus the total adds to more than 100 percent). The officers of 44 vessels (46 percent) reported that they were in some way aware that living organisms can be transported in ballast water. The officers of 26 vessels (27 percent) were aware that the IMO was concerned with the transport of organisms in ballast. In addition, the officers of 43 vessels (45 percent) were aware that some countries had initiated or were contemplating BW controls to restrict the transport of organisms. This latter number is likely to be an over-estimate, possibly related to communication problems. Although the officers specifically stated that they believed the impetus behind BW controls in these countries was related to the transport of these organisms, it is likely in some cases that the controls were, in fact, related to controlling the discharge of oily BW. Countries reported were Argentina, 1; Australia/New Zealand, 27; Canada, 10; Scandinavia, 4; USA, 6 (one specifically for Los Angeles); China, 2; Japan, 2; Orkney/Shetland Islands, 4; American Samoa, 1, and Chile, 1.

BALLAST WATER: HOW MUCH?

NABISS Ports: Vessel Arrivals from Foreign Ports, and Arrivals Reported in Ballast

As described in Chapter 2, U.S. Census Bureau data for 1991 (derived in turn from U.S. Customs data) were used to estimate the number of ship arrivals, the number of arrivals in ballast from foreign ports, and the LPOC of these arrivals for the 21 ports visited by NABISS. These data are shown in Tables 4-6, 4-7 (a, b, c, d), and Appendix C.

Of over 44,000 vessel arrivals in the 21 ports, approximately 21 percent (9,218) were vessels arriving from foreign ports in ballast (thus, with acknowledged ballast). Table 4-6 and Appendix C provide a port-by-port and month-by-month summary of these data. San Diego, Miami, Galveston, New Orleans, and Honolulu represent the top five ports in terms of percentage of vessels arriving in ballast (Table 4-7d). Miami, Houston, New York, New Orleans, and Seattle are the top five ports in terms of number of vessel arrivals from foreign ports (Table 4-7a). New Orleans (92 different LPOCs among arriving vessels in ballast), Houston (84 LPOC), Tampa (76), Norfolk (48) and Baltimore (44) rank as the top five ports in terms of number of LPOCs per port (Table 4-7c). New Orleans is in the top five ports of all three categories.

These rankings relate to several possible, but poorly understood, relationships between vessel traffic patterns and nonindigenous species invasion probabilities. These include (1) that <u>the more ships that enter a port</u>, the more acknowledged and unacknowledged ballast water may be carried in, (2) that <u>the ports with the greater percentages of vessels in ballast</u> may carry in a larger number and diversity of nonindigenous species, and (3) <u>the greater the number of sources</u>, the larger the potential pool of organisms that may be transported. Note however that in these data vessel size and type are not under consideration, such that the number of arrivals does not necessarily reflect the amount of ballast water entering the port (thus Miami is completely dominated in its vessel traffic by cruise ships coming from the Bahamas and Haiti (as discussed below)). In turn, passenger vessels are treated as "in ballast" by U. S. Customs and Census because they do not carry cargo, but these vessels actually do not normally travel in ballast and rarely carry or release large amounts of water. Thus the high ranking of Miami is due to this passenger vessel traffic. A similar phenomenon is seen in San Diego, where several cruise ships

Table 4-6

NABISS PORTS:
Number of Ship Arrivals, Arrivals from Foreign Ports in Ballast, Percent in Ballast, and Number of Different LPOCs for Ships in Ballast

Port	DPC	ARR	Bal	% Bal	LPOC
Boston	0401	666	36	5	14
New York	1001	4058	205	5	41
Baltimore	1303	2043	204	10	44
Norfolk	1401	2347	425	18	48
Charleston	1601	1433	50	3	27
Savannah	1703	1757	97	6	35
Miami	5201	5984	2662	44	39
Tampa	1801	1476	394	27	74
New Orleans	2002	3899	1260	32	92
Houston	5301	4226	696	16	84
Galveston	5310	734	293	40	40
San Diego	2501	1038	650	63	10
Long Beach	2709	2408	220	9	18
Los Angeles	2704	2571	533	21	27
Oakland	2811	1283	14	1	6
San Francisco	2809	734	44	6	7
Portland	2904	985	255	26	18
Tacoma	3002	1610	316	.20	9
Seattle	3001	2672	214	8	17
Anchorage	3126	1123	303	27	14
Honolulu	3201	1227	347	28	20
Total		44274	9218		

DPC: District Port Code
ARR: Number of Ship Arrivals
Bal: Number of Ships In Ballast
% Bal: % of Ships Arriving That are In Ballast
LPOC : Last Port Of Call

Table 4-7

NABISS PORTS: Ports (Ranked Left to Right):
(a) Ports Ranked by Number of Ship Arrivals
(b) Ports Ranked by Number in Ballast
(c) Ports Ranked by Number of Different LPOCs
(d) Ports Ranked by Percent in Ballast (see text)

A		B		C		D	
Ports Ranked by No. Arrival		Ports Ranked by No. In-Ballast		Ports Ranked by No. of Different LPOC's		Ports Ranked by % In Ballast	
Port	No. ARR	Port	No. In Bal	Port	No. LPOC	Port	% In Bal
Miami	5984	Miami	2662	New Orleans	92	San Diego	63
Houston	4226	New Orleans	1260	Houston	84	Miami	44
New York	4058	Houston	696	Tampa	74	Galveston	40
New Orleans	3899	San Diego	650	Norfolk	48	New Orleans	32
Seattle	2672	Los Angeles	533	Baltimore	44	Honolulu	28
Los Angeles	2571	Norfolk	425	New York	41	Anchorage	27
Long Beach	2408	Tampa	394	Galveston	40	Tampa	27
Norfolk	2347	Honolulu	347	Miami	39	Portland	26
Baltimore	2043	Tacoma	316	Savannah	35	Los Angeles	21
Savannah	1757	Anchorage	303	Los Angeles	27	Tacoma	20
Tacoma	1610	Galveston	293	Charleston	27	Norfolk	18
Tampa	1476	Portland	255	Honolulu	20	Houston	16
Charleston	1433	Long Beach	220	Long Beach	18	Baltimore	10
Oakland	1283	Seattle	214	Portland	18	Long Beach	9
Honolulu	1227	New York	205	Seattle	17	Seattle	8
Anchorage	1123	Baltimore	204	Boston	14	San Francisco	6
San Diego	1038	Savannah	97	Anchorage	14	Savannah	6
Portland	985	Charleston	50	San Diego	10	Boston	5
Galveston	734	San Francisco	44	Tacoma	9	New York	5
San Francisco	734	Boston	36	San Francisco	7	Charleston	3
Boston	666	Oakland	14	Oakland	6	Oakland	1
Total	44274	Total	9218				

(Passenger/RoRo) make continuous runs back-and-forth between that port and the west coast of Mexico (see below) and in Galveston where a passenger vessel makes voyages to the "open ocean" and back. Fishing vessels contribute to the high ranking of Honolulu.

Relationship among Tonnage, Ballast Capacity, Ballast on Arrival and Normal Ballast Load When Travelling in Ballast

As discussed in Chapter 2, we estimated ballast water capacities (BWCAP), average ballast arrival volumes for all vessels (BWARR, both in and with ballast), and normal ballast water loads while a vessel is in ballast (BWBT) from calculations based upon NABISS/NV data. Table 4-8 shows the relationship between these variables and summer deadweight tonnage (SDWT) and compares NABISS/NV results with NABISS/APHIS results. Container ships are virtually never "in ballast," and thus there are no BWBT data for NABISS/NV (the APHIS survey did not collect BWBT data). BWARR and BWBT are naturally sensitive to weather conditions, cargo loads, and specific cargo routes for specific vessel types (note for example that for tankers an average BWARR is 24 percent of BWCAP, but an average BWBT is 89 percent of BWCAP).

Based upon APHIS data (Table 4-8), these basic relationships are as follows:

> *The ratio of BWCAP to SDWT* for all vessels combined is 0.38, for container ships, 0.32, for tankers, 0.38, and for bulkers, 0.43.
> *The ratio of BWARR to SDWT* for all vessels is 0.16, for containers, 0.15, for tankers, 0.05, and for bulkers, 0.23.
> *For BWARR as a percentage of BWCAP* for all vessels the ratio is 0.43, for containers, 0.47, for tankers, 0.13 and for bulkers, 0.54. Our estimates of ballast volumes (below) are based on these vessel-sensitive ratios for BWBT.

Based upon NV data, the relationship is:

> *The ratio of BWBT to SDWT* for all vessels is 0.33, for tankers 0.32, and for bulkers, 0.36.

Schormann et al. (1991) reported that a typical ratio of ballast water capacity compared to DWT was 25 to 30 percent. Pollutech (1992) noted that the actual amount of ballast water aboard a vessel varies according to weather, length of voyage, and other considerations: "Ballast tonnage at 25 percent is considered the norm, 20 percent for short trips and good weather, and 30 percent for heavy weather. In severe conditions, a Master may decide to use 40 percent ballast." Pollutech (1992) used 25 percent to calculate typical ballast volumes. Jones (1991) calculated ballast water as 60 percent of DWT, referring to this as both the "capacity" of the vessels and as the amount "discharged" (these are two distinct ballast states, which are further differentiated from ballast "on arrival" and "average ballast carried when in ballast"). Based on the above ratios, a lower percentage of BWCAP and BWBT to DWT may be applicable to Australian data sets.

TABLE 4-8

RELATIONSHIP BETWEEN SDWT, BWCAP, BWARR, AND BWBT, BASED ON NABISS/NV AND APHIS DATA

Relationship between summer deadweight tonnage (SDWT), ballast water capacity (BWCAP), the quantity of ballast water carried on arrival (BWARR) and the usual quantity of ballast water carried when travelling in ballast (BWBT) based on information collected by boarding vessels (NV) and from the APHIS ballast water survey (APHIS). All vessel parameters are recorded in metric tons. (Numbers (N) and standard deviations (SD) are also recorded for the various values.)

	All Vessels		Containers		Tankers		Bulkers	
	NV	APHIS	NV	APHIS	NV	APHIS	NV	APHIS
SDWT	31018	33363	33341	29647	37420	43071	40681	45288
N	94	1002	30	223	12	190	29	322
SD	21894	29602	13669	16686	28370	37842	24695	32304
BWCAP	12096	12555	10613	9452	13532	16370	19157	19374
N	95	1012	31	236	12	178	29	322
SD	10036	14165	5487	6016	9715	17187	12241	17284
% of SDWT	.39	.38	.32	.32	.36	.38	.47	.43
BWARR	5958	5340	5228	4414	3239	2130	11215	10423
N	95	1023	30	231	12	190	29	324
SD	7527	9217	2734	2960	4719	7275	11295	13571
% of SDWT	.19	.16	.16	.15	.09	.05	.28	.23
% of BWCAP	.49	.43	.49	.47	.24	.13	.59	.54
% of BWBT	.58	NA	NA	NA	.27	NA	.78	NA
BWBT	10352	NA	NA	NA	12088	NA	14445	NA
N	57	0	0	0	11	0	28	0
SD	9269	NA	NA	NA	7877	NA	9726	NA
% of SDWT	.33	NA	NA	NA	.32	NA	.36	NA
% of BWCAP	.86	NA	NA	NA	.89	NA	.75	NA
% of BWARR	1.74	NA	NA	NA	3.73	NA	1.29	NA

NABISS Ports: Vessel and Ballast Water Tonnage Information

Based upon NV data sets, Tables 4-9 (all vessels), 4-10 (bulk carriers), 4-11 (tankers), and 4-12 (container ships) present the summarized tonnage information collected from 95 of the boarded 97 vessels (acronyms are explained at the bottom of each table).

For all vessels, ballast water capacity averaged about 12,000 MT (3,200,000 gallons), ranging from 211 MT (56,000 gallons) to 47,000 MT (12,400,000 gallons) capacity. Ballast water arriving (ballast on board) averaged 6,000 MT (1,580,000 gallons) with ranges from 2 MT (528 gallons) to 45,000 MT (11,890,000 gallons) -- an impressive range, underscoring the size of the confidence intervals shown in the tables. Normal loads while travelling in ballast are 10,300 MT (2,720,000 gallons), these ranging from 51 MT (13,500 gallons) to 35,000 MT (9,250,000 gallons).

Bulk carriers (Table 4-10) have average capacities of 19,100 MT (5,060,000 gallons) with ranges from 211 MT (56,000 gallons) to 47,000 MT (12,400,000 gallons). Average arrivals carry 11,200 MT (2,960,000 gallons), with normal loads in ballast being 14,400 MT (3,800,000 gallons).

Tankers (Table 4-11) have average capacities of 13,500 MT (3,575,000 gallons) with ranges from 1,500 MT (396,000 gallons) to 28,000 MT (7,450,000 gallons. Average arrivals carry 3,200 MT (850,000 gallons), with average normal loads in ballast being 12,000 MT (3,170,000 gallons).

Container ships (Table 4-12) have average capacities of 10,600 MT (2,800,000 gallons), ranging from 3,900 MT (1,020,000 gallons) to 22,200 MT (5,865,000 gallons). Average arrivals carry 5,200 MT (1,370,000 gallons). Container ships do not normally sail "in ballast" (that is, they are almost never without cargo), and thus there is no "normal load when in ballast."

A relatively large volume of ballast water remains <u>unpumpable</u> aboard bulk carries, tankers, and container ships. Average amounts are 68 MT (18,000 gallons) for bulkers, 86 MT (22,700 gallons) for tankers, and 145 MT (38,000 gallons) for container ships. Overall, for all vessels, the average amount is 92 MT (or 24,500 gallons), ranging from 0.1 MT (26 gallons) to 528 MT (140,000 gallons). The importance of this "unpumpable" amount is discussed elsewhere, relative to residual biota being resuspended and mixed in with "new" ballast water pumped into these tanks -- later to be pumped out as well, but with the residual biota mixed in.

It is of interest to compare these data to the much larger APHIS data set available for bulkers, container ships, and tankers relative to the amounts of BW actually discharged at a port and the amount of BW actually taken on at that port (Table 4-13). The APHIS data set is derived from 1034 vessels; the NV data set, upon 95 vessels. A comparison of Tables 4-10, 4-11, and 4-12 with 4-13 reveals the following patterns:

For <u>container</u> ships, APHIS discharge data are 303 MT (80,000 gallons), comparing to the NV arrival data of 5,228 MT (1,380,000 gallons). Bulker discharge data are 8,843 MT (2,300,000 gallons) compared to arrival data of 11,215 MT (3,000,000 gallons). In contrast, APHIS discharge data for tankers are 1503 MT (400,000 gallons), while NV average tanker arrival show 3239 MT (900,000 gallons).

We have assumed that for many, if not most vessels, water not discharged at one site in the country of arrival may well be discharged at another site -- in effect, much of the water may be discharged in the target country eventually, especially in large countries with many ports.

Table 4-9
NABISS Vessels: Vessel Tonnage and In- and With-Ballast Vessels: All Vessels

Tonnage information collected by boarding all vessels. The bottom four lines represent column totals, number of observations, column means and standard deviations of the samples.

NRT	GRT	SDWT	BW Cap	BW ARR	Mth Max	Mth Min	BW BT	BW UP
18410	46411	53240	19721	5014	9000	2000		
10058	15324	25939	11911	5300				
10210	20345	28422	8697	5432	6000	4000		
42210	54954	114450	47000	45000			35000	300
13558	18625	34288	10855	9000			10200	50
9222	15486	30187	15796	12000			12000	
5894	8929	15763	3102	1196			3102	50
13730	11776	15395	5069	2770	2770	2770	2770	
9410	31367	9726	5600	3973	4000	3600		
25487	52191	60640	22200	9055	9055	7500		200
11847	17157	25600	6444	2	6444	2	6444	2
18545	27790	48978	18422	7417	18422	528	18422	528
16135	32630		14350	3262	8000	3000		10
9829	14757	29017	8210	40	3550	40	3550	40
3335	5532	7951	2157	1072	1300	140	1300	20
20190	42145	38217	12993	5480	8104	4830	11152	200
4664	10282	13346	4088	1862	2470	1500		100
10303	17590	28836	9234	7876	9234	760	9234	
12752	20613	31910	14558	8200	13140	200	13140	200
27814	35409	75200	30885	30885	30885	200	30885	200
3651	9628	9464	1552	1122	1250	900	1200	3
1691	3773	6105	2434	1300	1400	1100		50
		9200	2763	2763	2763	2763	2763	100
16243	28079	5976	1177	852	902	750		100
28860	48536	3500	1856	1474	1474	1474	1474	50
247	540	1165	211	85	85	85	85	4
40325	53321	112106	26701	30	24000	30	24000	30
22214	30675	64896	28183	895	24000	250	24000	250
2697	3891	6478	1500	50	700	50	700	50
12455	22359	36639	20470	9202	18707	30	9202	30
25546	41220	73493	28745	28745	28745	60	28745	60
4082	6167	10026	911	106	300	6	350	6
2604	4051	5924	1247	10	1200	10	1200	10
21078	28580	46891	21629	5141	5141	2000	8129	10
5755	10038	11802	2382	884	1244	884	2382	75
13324	18732	32093	8523	3000	8523	3000	8523	25
18407	26251	43579	26806	19860	19860	150	19860	100
11480	31920	36580	10676	8535	8535	2235		300
8710	15380	25300	8500	6000	6000	500	8500	0.2
4425	6890	15870	4468	1276	4468	282	2040	11
6285	10735	18130	4597	1507	3690	1507		90
31178	39869	82325	43746	27000	35000	20000	30000	200
11932	22204	36537	20000	5000	5000	5000	10000	40
13871	24639	42512	25023	11593	22000	10000	20000	50
1532	2939	4526	357	357	357	357	357	3
15434	23377	38212	27537	1626	14000	1626	14000	0.1
8390	16608	2370	1264	688	688	530	688	6
19809	40132	3160	1689	51	395	51	51	2.5
15889	37071	47127	19870	11542	14000	4000		30
23885	40980	44477	10453	5234	6500	4610		
3588	6419	6808	1431	561	1030	540	1030	2
20042	29160	46745	28343	4756	4756	4756	17000	20
6235	10804	17722	4296	2200	2200	50	3100	50
10329	16584	19993	10727	4	9145	4	9145	4

Table 4-9 (continued)
NABISS Vessels: Vessel Tonnage and In- and With-Ballast Vessels: All Vessels

7783	16886	12373	9082	2300	2800	2300	2800	35
13871	24625	42647	25002	13245	13245	50	13245	50
6290	11658	12714	2395	450	1300	25	1300	25
6614	10075	18955	6382	1200	1200	5	2100	5
18602	46552	53274	19240	6000	11970	5350		200
12121	22087	35212	8450	2680	2900	2400		100
13449	44830	14155	6845	5280	6020	3713	6020	25
9125	14578	16239	9221	1603	9221	1603	9221	50
4757	7150	11973	3865	2832	2832	0		10
22698	28492	48557	5348	3261	3297	2330		50
17599	24559	26772	7031	3700	4000	3000		100
7833	14161	15790	4080	2009	2255	1640		55
15276	21351	40639	16948	16134	16134	5	16134	5
9134	19353	30036	17910	70	15000	70	15000	70
11618	32629	32839	8506	5718	5718	5293		150
11259	27823	29288	6267	4463	4491	4224		80
31126	40628	35383	10288	1830				500
8395	13094	19863	6116	5181	5739	4791		200
15456	37023	43401	12190	5989	6400	3400		100
23309	52181	60350	22126	6803	10000	4000		60
6955	9260	10601	5067	4157	4157	3027	4157	200
9842	13371	23987	6431	2830	3656	1439		100
22627	35944	65084	29803	16000	16000	16000	16000	30
12311	19340	33024	19130	40	8960	40	9184	40
7619	9941	18433	4741	4323	4323	17	4323	17
16710	39219	47002	24622	23545	23545	24.4	23545	24.4
22638	34359	60478	32076	18288	18288	20	18288	20
10520	17676	18835	4245	4245	4439	4016		
19014	34654	61143	30296	16170	26000	13000	26000	100
7848	14173	23720	3922	2090	2090	1388		70
10855	18855	29331	8204	5000	5500	4500		110
9748	17414	25412	8230	4600	5600	2800		100
7854	20965	21217	11257	6546				100
13140	34487	34775	10006	4400	7000	2000		80
10935	24802	28916	7584	2000	2650	1100		300
22698	28492	28661	7650	2964				100
5336	17789	16511	6041	2239	3623	2239		250
22238	35963	45987	16416	10000				500
11399	17527	18202	6164	3668	3860	3450		100
7854	20965	21247	11560	6406	6406	3901		150
13932	19388	27861	17000	7500	17000	6000	17000	15
1264184	2205184	2915723	1149096	566044	698051	209820	590040	7938
94	94	94	95	95	86	86	57	86
13448.8	23459.4	31018.3	12095.7	5958.36	8116.87	2439.77	10351.6	92.3
8157.56	13185	21893.7	10035.6	7527.43	7839.62	3374.37	9269.11	110.3

NRT	Net Register Tonnage (in net tons)
GRT	Gross Register Tonnage (in gross tons)
SDWT	Summer Deadweight Tonnage (in metric tons)
BW Cap	Ballast Water Capacity (in metric tons of seawater)
BW ARR	Ballast Water Carried On Arrival At Port Of Boarding (in metric tons)
Mth Max	Maximum Quantity Of Ballast Water Carried In The Past Month (in metric tons)
Mth Min	Minimum Quantity Of Ballast Water Carried In The Past Month (in metric tons)
BW BT	Quantity Of Ballast Water Normally Carried When Travelling In Ballast (in metric tons)
BW UP	Quantity Of Ballast Water Remaining In The Ballast Tanks After Complete Discharge (in metric tons)

Table 4-10
NABISS Vessels: Vessel Tonnage and In- and With-Ballast Vessels: Bulk Carriers

Tonnage information collected by boarding bulk carriers. The bottom four lines represent column totals, number of observations, column means and standard deviations of the sample.

NRT	GRT	SDWT	BW Cap	BW ARR	Mth Max	Mth Min	BW BT	BW UP
42210	54954	114450	47000	45000			35000	300
13558	18625	34288	10855	9000			10200	50
9222	15486	30187	15796	12000			12000	
9829	14757	29017	8210	40	3550	40	3550	40
3335	5532	7951	2157	1072	1300	140	1300	20
10303	17590	28836	9234	7876	9234	760	9234	
12752	20613	31910	14558	8200	13140	200	13140	200
27814	35409	75200	30885	30885	30885	200	30885	200
247	540	1165	211	85	85	85	85	4
12455	22359	36639	20470	9202	18707	30	9202	30
25546	41220	73493	28745	28745	28745	60	28745	60
4082	6167	10026	911	106	300	6	350	6
18407	26251	43579	26806	19860	19860	150	19860	100
31178	39869	82325	43746	27000	35000	20000	30000	200
11932	22204	36537	20000	5000	5000	5000	10000	40
13871	24639	42512	25023	11593	22000	10000	20000	50
20042	29160	46745	28343	4756	4756	4756	17000	20
13871	24625	42647	25002	13245	13245	50	13245	50
6614	10075	18955	6382	1200	1200	5	2100	5
9125	14578	16239	9221	1603	9221	1603	9221	50
9134	19353	30036	17910	70	15000	70	15000	70
9842	13371	23987	6431	2830	3656	1439		100
22627	35944	65084	29803	16000	16000	16000	16000	30
12311	19340	33024	19130	40	8960	40	9184	40
7619	9941	18433	4741	4323	4323	17	4323	17
16710	39219	47002	24622	23545	23545	24	23545	24
22638	34359	60478	32076	18288	18288	20	18288	20
19014	34654	61143	30296	16170	26000	13000	26000	100
13932	19388	37861	17000	7500	17000	6000	17000	15
430220	670222	1179749	555564	325234	349000	79695	404457	1841
29	29	29	29	29	26	26	28	27
14835.2	23111.1	40681	19157.4	11215	13423.1	3065.19	14444.9	68.19
8981.54	12469.9	24695.3	12241.4	11294.6	10154.5	5548.7	9725.92	73.89

NRT Net Register Tonnage (in net tons)
GRT Gross Register Tonnage (in gross tons)
SDWT Summer Deadweight Tonnage (in metric tons)
BW Cap Ballast Water Capacity (in metric tons of seawater)
BW ARR Ballast Water Carried On Arrival At Port Of Boarding (in metric tons)
Mth Max Maximum Quantity Of Ballast Water Carried In The Past Month (in metric tons)
Mth Min Minimum Quantity Of Ballast Water Carried In The Past Month (in metric tons)
BW BT Quantity Of Ballast Water Normally Carried When Travelling In Ballast (in metric tons)
BW UP Quantity Of Ballast Water Remaining In The Ballast Tanks After Complete Discharge (in metric tons)

Table 4-11
NABISS Vessels: Vessel Tonnage and In- and With-Ballast Vessels: Tankers

Tonnage informaton collected by boarding tankers. The bottom four lines represent column totals, number of observations, column means and standard deviations of the samples.

NRT	GRT	SDWT	BW Cap	BW ARR	Mth Max	Mth Min	BW BT	BW UP
11847	17157	25600	6444	2	6444	2	6444	2
18545	27790	48978	18422	7417	18422	528	18422	528
40325	53321	112106	26701	30	24000	30	24000	30
22214	30675	64896	28183	895	24000	250	24000	250
2697	3891	6478	1500	50	700	50	700	50
15434	23377	38212	27537	1626	14000	1626	14000	0
10329	16584	18883	10727	4	9145	4	9145	4
15276	21351	40639	16948	16134	16134	5	16134	5
13324	18732	32093	8523	3000	8523	3000	8523	25
8710	15380	25300	8500	6000	6000	500	8500	0
6285	10735	18130	4597	1507	3690	1507		90
6235	10804	17722	4296	2200	2200	50	3100	50
171221	249797	449037	162378	38865	133258	7552	132968	1034
12	12	12	12	12	12	12	11	12
14268.4	20816.4	37419.8	13531.5	3238.75	11104.8	629.333	12088	86.17
9899.86	12659.1	28370.3	9715.13	4719.43	8093.84	941.924	7877.22	155.8

NRT Net Register Tonnage (in net tons)
GRT Gross Register Tonnage (in gross tons)
SDWT Summer Deadweight Tonnage (in metric tons)
BW Cap Ballast Water Capacity (in metric tons of seawater)
BW ARR Ballast Water Carried On Arrival At Port Of Boarding (in metric tons)
Mth Max Maximum Quantity Of Ballast Water Carried In The Past Month (in metric tons)
Mth Min Minimum Quantity Of Ballast Water Carried In The Past Month (in metric tons)
BW BT Quantity Of Ballast Water Normally Carried When Travelling In Ballast (in metric tons)
BW UP Quantity Of Ballast Water Remaining In The Ballast Tanks After Complete Discharge (in metric tons)

Table 4-12
NABISS Vessels: Vessel Tonnage and In- and With-Ballast Vessels: Containers

Tonnage information collected by boarding container carriers. The bottom four lines represent column totals, number of observations, column means and standard deviations of the samples.

NRT	GRT	SDWT	BW Cap	BW ARR	Mth Max	Mth Min	BW BT	BW UP
18410	46411	53240	19721	5014	9000	2000		
10058	15324	25939	11911	5300				
10210	20345	28422	8697	5432	6000	4000		
25487	52191	60640	22200	9055	9055	7500		200
16135	32630		14350	3262	8000	3000		10
20190	42145	38217	12993	5480	8104	4830		200
4664	10282	13346	4088	1862	2470	1500		100
11480	31920	36580	10676	8535	8535	2235		300
15889	37071	47127	19870	11542	14000	4000		30
23885	40980	44477	10453	5234	6500	4610		
18602	46552	53274	19240	6000	11970	5350		200
4757	7150	11973	3865	2832	2832	10		10
22698	28492	48557	5348	3261	3297	2330		50
17599	24559	26772	7031	3700	4000	3000		100
7833	14161	15790	4080	2009	2255	1640		55
11618	32629	32839	8506	5718	5718	5293		150
11259	27823	29288	6267	4463	4491	4224		80
31126	40628	35383	10288	1830				500
15456	37023	43401	12190	5989	6400	3400		100
23309	52181	60350	22126	6803	10000	4000		60
10520	17676	18835	4245	4245	4439	4016		3
7848	14173	23720	3922	2090	2090	1388		70
10855	18855	29331	8204	5000	5500	4500		110
9748	17414	25412	8230	4600	5600	2800		100
7854	20965	21217	11257					100
13140	34487	34775	10006	4400	7000	2000		80
10935	24802	28916	7584	2000	2650	1100		300
22698	28492	28661	7650	7524				100
5336	17789	16511	6041	2239	3623	2239		250
22238	35963	45987	16416	10000				500
7854	20965	21247	11560	11420	11420	8915		150
449691	892078	1000227	329015	156839	164949	89880		3908
31	31	30	31	30	26	26		27
14506.2	28776.7	33340.9	10613.4	5227.97	6344.19	3456.92		144.7
6884.13	12340.4	13669	5486.87	2734.32	3235.59	1973.55		130.4

NRT Net Register Tonnage (in net tons)
GRT Gross Register Tonnage (in gross tons)
SDWT Summer Deadweight Tonnage (in metric tons)
BW Cap Ballast Water Capacity (in metric tons of seawater)
BW ARR Ballast Water Carried On Arrival At Port Of Boarding (in metric tons)
Mth Max Maximum Quantity Of Ballast Water Carried In The Past Month (in metric tons)
Mth Min Minimum Quantity Of Ballast Water Carried In The Past Month (in metric tons)
BW BT Quantity Of Ballast Water Normally Carried When Travelling In Ballast (in metric tons)
BW UP Quantity Of Ballast Water Remaining In The Ballast Tanks After Complete Discharge (in metric tons)

Table 4-13
Mean volumes of BW (MT) taken on and discharged in ports by various vessel types

Mean volumes of ballast water (in metric tons) taken on and discharged in U.S. ports by the various vessel types (Bulk: bulkers; Cont: container carriers; Tank: tankers); numbers of vessels (n), standard deviation of the samples (SD), and maximum values (Max) are also recorded. (Derived from APHIS survey data)

Vessel	Ballast Water Discharged				Ballast Water Taken On			
Type	n	Mean	SD	Max	n	Mean	SD	Max
All	984	3303	8806	87376	976	2977	8221	56357
Bulk	320	8843	12692	76155	319	2160	6998	41000
Cont	218	303	777	5394	208	412	988	7500
Tank	186	1503	7204	87376	183	11197	14406	56375

The Amount of Acknowledged Ballast Water Arriving in U.S. Waters in Vessels from Foreign Ports: Estimates Derived from U.S. Census Bureau Data

As detailed in Chapter 2, we used subsampling statistics to estimate the amounts (volumes) of **acknowledged** ballast water (that is, for vessels reported as travelling in ballast) at selected ports in the United States for five coastlines (East, Gulf, West, Alaska, and Hawaii). Three vessel types were chosen -- bulk carriers (bulkers), tankers, and general cargo carriers -- which comprise approximately 60 percent of the vessel traffic by ship type. A total of 1,157 vessels were subsampled (Appendix D). Container ships have no acknowledged ballast, as they are virtually never "in ballast" (as noted above); we examine the importance of these vessels below.

Table 4-14 provides a summary of the acknowledged ballast data. Within tanker traffic, acknowledged ballast is highest at LA/Long Beach, with a total of over 3,000,000 metric tons. Remaining ports/port systems among the top five (New Orleans, Houston/Galveston, Anchorage, New York) all receive less than 1,000,000 MT of water. Within bulker traffic, acknowledged ballast is highest at New Orleans, with a total of over 12,000,000 MT of water, followed by Norfolk with over 9,000,000 MT of water. All other ports receive far smaller amounts, with the next four highest ports/port systems being Baltimore, Los Angeles/Long Beach, Seattle/Tacoma, and Houston/Galveston. Within general cargo vessel traffic, the top five sites are New Orleans, Houston/Galveston, Miami, Tampa, and Savannah.

Thus, ports along the Atlantic, Gulf, Pacific, and Alaskan coasts all rank in the top six ports/port systems for the three types combined. On the Pacific coast Los Angeles/Long Beach and Tacoma/Seattle are among the top tanker and bulker ports, respectively, receiving ballast water (no Pacific port is high among general cargo vessels, with Los Angeles ranking seventh in this category). On the Gulf coast both Houston and New Orleans rank in the top five within all three vessel types, with Tampa also in the top five for general cargo carriers reported in ballast. On the Atlantic coast different ports rank high relative to vessel type: New York for tankers, Norfolk and Baltimore for bulkers, and Miami and Savannah for general cargo. On the Alaskan coast Anchorage ranks fourth overall for tankers.

New Orleans, with an estimated 13,484,000 MT (3,553,000,000 gallons), thus ranks as the number 1 U.S. port in terms of acknowledged ballast received from all three ship types. Norfolk ranks second with an estimated 9,325,000 MT (2,457,138,000 gallons) of water received. LA/Long Beach is third with 5,878,000 MT (1,548,853,000 gallons), Houston is fourth with 3,239,000 MT (853,477,000 gallons), and Baltimore is fifth with 2,834,000 gallons (746,759,000 gallons).

It is important to note, and indicative of the nature of how vessel traffic is officially recorded, that San Diego, which ranks as the largest port among the 21 sampled in terms of the percentage of ships in ballast (Appendix D), fails to appear entirely in Table 4-14. As discussed above, San Diego merchant traffic in ballast consists predominately of passenger vessels making frequent calls. These are recorded as "in ballast" by Customs because they lack cargo. In San Diego Bay military traffic may be the most important contributor of ballast water.

Total acknowledged ballast arriving in U.S. waters in 1991 in bulk carriers, tankers, and general cargo from foreign ports is thus estimated to be as follows:

Table 4 - 14

Acknowledged Ballast: Summary by Vessel Type and Ports

PORT	ACKNOWLEDGED BALLAST BULKERS	TANKERS	GEN CARGO	TOTAL
NEW ORLEANS	12279891	963472	240384	13483747
NORFOLK	9227554	75434	22157	9325145
LONG BEACH/LA	2587217	3258723	31885	5877824
HOUS/GAL	2089514	916438	232944	3238896
BALTIMORE	2822969	0	10760	2833729
TACO/SEATTLE	2573183	104026	10808	2688018
TAMPA	1454492	106667	137301	1698460
PORTLAND	1427755	203294	27553	1658602
ANCHORAGE	859373	305719	0	1165091
NEW YORK	437036	291538	9018	737591
SAVANNAH	224246	32154	50254	306654
CHARLESTON	205026	0	8621	213647
MIAMI	0	0	154168	154168
OAK/SAN FRAN	82367	35934	13226	131526
HONOLULU	6562	67276	4993	78831
BOSTON	65014	8533	4351	77898
SAN DIEGO	0	0	0	0
TOTAL	36342197	6369206	958424	43669827

Ballast Water Amounts Shown in Metric Tons

Acknowledged ballast water in tankers:		6,369,206 metric tons
Acknowledged ballast water in bulkers:		36,342,197 metric tons
Acknowledged ballast water in general cargo:		958,424 metric tons
	Total:	43,669,827 metric tons (11,507,000,000 gallons)

Appendix D presents these data as histograms.

The Amount of Unacknowledged Foreign Ballast Water Arriving in U.S. Waters in Vessels from Foreign Ports: Estimates Derived from a Combination of U.S. Census Bureau Data and NABISS/NV Data

Based upon subsamples drawn from U.S. Census Bureau data (see Chapter 2), the amounts of **unacknowledged** ballast water carried (that is, for vessels in cargo) were calculated using known averages from NABISS vessel boarding data. Three vessel types -- bulkers, containers, and tankers -- were analyzed in five ports chosen to represent the East, Gulf, and West coasts. The five ports selected for this analysis were Baltimore and Norfolk, New Orleans, and San Francisco and Oakland. These data are shown in Appendices E and F.

The quantities of ballast water arriving in the United States with vessels in cargo are considerable: an estimated (rounded) 6,600,000 MT (1,740,000 gallons) of water enter by this route alone, or approximately 13 percent of the total volume of acknowledged and unacknowledged water combined. Almost 1.75 billion gallons of water arrive yearly by this route in the three vessel types in the five ports studied.

New Orleans again ranks as the largest among these five ports in receipt of unacknowledged ballast water. Norfolk, Baltimore, and Oakland, are close behind, with San Francisco receiving a much smaller fraction.

For tankers, unacknowledged ballast significantly exceeds acknowledged ballast in Baltimore (Appendix F; Baltimore thus tends to be an importer as opposed to an exporter of liquid bulk). Container ships (Appendix E) contain only unacknowledged ballast. Acknowledged ballast in bulkers always exceeds unacknowledged ballast where significant amounts are involved (thus excluding Oakland and San Francisco), but unacknowledged ballast can nonetheless be in ecologically significant quantities.

Total Estimated Volumes of Foreign Ballast Water Arriving in U.S. Waters from Vessels from Foreign Ports

Based upon the above estimates of both acknowledged and unacknowledged water, it is possible to estimate the amount of ballast water arriving in the United States in vessels from foreign ports (based upon 1991 data: see Chapter 2).

There are 226 U. S. ports that receive vessel traffic from foreign ports (U. S. Census Bureau data, 1991). We examined in detail 22 of these ports. The amount of water entering the remaining 205 ports is thus not known. We have conservatively estimated the impact of bulkers,

tankers, and general cargo vessels arriving from foreign ports in cargo (unacknowledged ballast) and without cargo (acknowledged ballast) at these ports by assuming that one-half (100) of the ports receives at least 10 percent (that is, 239,400 MT) of the average volume of the total acknowledged and unacknowledged ballast water at each of the 21 ports (that is, 2,394,000 MT). We assume this is a conservative estimate. There are in addition more than 25 other types of ocean-going vessels in the foreign traffic that visit U.S. waters. We assumed that all of these remaining vessels release at least 10 percent of the total volume of acknowledged and unacknowledged ballast as calculated for the 21 ports for bulkers, tankers, general cargo, and container ships; this too we assume to be an underestimate.

Table 4-15 summarizes these estimates: approximately 79,000,000 metric tons, or almost 21,000,000,000 gallons of ballast water, arrive every year in U.S. waters in vessels from foreign ports. This is about 58,000,000 gallons per day, or over 2,400,000 gallons an hour.

Not included in the estimates on Table 4-15 are domestic and foreign military vessels. These vessel types may contribute, both in volume and in source regions, potentially important amounts of ballast water.

BALLAST WATER: WHERE FROM?

Data Handling

Where does the ballast water come from? Last port of call (LPOC) data are available (by world port codes) through U.S. Census Bureau "Vessel Arrival" data. As described in Chapter 2, these data are for all in-ballast ships for the 21 NABISS ports. The effect of unacknowledged ballast on potential geographic diversity of water sources was tested for the five ports of Baltimore, Norfolk, New Orleans, San Francisco, and Oakland, representing the East, Gulf and West coasts. As also described in Chapter 2, LPOCs were converted to FAO region. This conversion was, in part, an attempt to circumvent the differences in refinement of Customs/Census LPOC regions (where, for example, port code 1223 is Montreal, but port code 1224 is the Canada Atlantic Region). Only foreign LPOCs are included in the analysis.

The accuracy of using LPOC as a direct indication of the source of ballast water was tested by using APHIS data to compare the LPOC of a vessel with the actual known source or sources of the ballast water on the same vessel. LPOCs were analyzed both as (1) the actual port of call and (2) as the FAO region (see Figure 2-3) within which the LPOC occurs.

LPOC by FAO Region for Ships in Ballast from Foreign Ports

Appendix G presents the results of LPOC for the 21 NABISS ports. LPOC by FAO regions are listed in order of decreasing frequency. Appendix H provides a port-by-port LPOC breakdown from Census data for the NABISS ports prior to collapsing these into FAO regions.

Atlantic Coast Ports

LPOCs (Appendix G) for **New York, Charleston, Savannah, and Miami** are predominately either the **Northeast Atlantic** (western Europe and adjacent regions) or the **Western Central Atlantic** (Bermuda, Bahamas, Caribbean, the Gulf of Mexico, Atlantic Mexico

TABLE 4-15

TOTAL ESTIMATED VOLUMES OF FOREIGN BALLAST WATER ARRIVING IN U.S.WATERS
(1991)

	Metric Tons	Gallons
Acknowledged Ballast Based upon: * 3987 foreign-in-ballast arrivals * 21 ports * 3 ship types: bulkers, tankers, general cargo	43,670,000	11,507,000,000
Unacknowledged Ballast Based upon: * 1372 foreign-in-cargo arrivals * 5 ports * 3 ship types: bulkers, tankers, container ships	6,600,000	1,739,000,000
Above excludes the following:		
* Approximately 200 different USA ports receiving foreign vessels	[23,940,000] (*)	[6,308,190,000]
* > 25 additional vessel types, representing +/- 40% of numbers of vessels involved in foreign traffic	[5,027,000] (**)	[1,324,614,000]
TOTALS:	79,237,000	20,878,804,000
Volume per month:	6,603,000	1,739,900,000
Volume per day:	220,100	57,997,000
Volume per hour:	9,200	2,417,000
Volume per minute:	150	40,000

(*) Assuming that one-half of these ports (100) each receive at least 10% (239,400 MT) of the average volume (2,394,000 MT) of the total acknowledged and unacknowledged ballast water at each of the 21 ports

(**) Assuming all other vessel types release a total of at least 10% of the total volume of acknowledged and unacknowledged ballast as calculated above for 21 ports and designated vessel types

and Central America, and northeastern South America). For New York these numbers are heavily influenced by passenger vessel traffic from Bermuda. Vessel traffic for Miami is completely dominated (> 99 percent) by cruise ships coming from the Bahamas and Haiti. LPOCs for **Boston** are the **Northwest Atlantic** (Canada) and the **Northeast Atlantic**, followed by the **Western Central Atlantic**. LPOCs for **Baltimore** and **Norfolk** are the **Northeast Atlantic** and the **Mediterranean/Black Sea region.** All but Charleston SC receive regular vessel traffic directly from the **Pacific Ocean** (Charleston receives some Pacific vessel traffic, but too rare to appear in our subsample of 1991 data). New York, Norfolk, and Charleston also receive some **Indian Ocean** traffic. All five East Coast ports receive vessels calling from the **Mediterranean/Black Sea** regions.

Norfolk (with 48 different LPOCs), Baltimore (with 44), and New York (41) rank highest in terms of numbers of different LPOCs, followed by Miami (39), Savannah (35), and Boston (14).

Gulf Coast Ports

All four Gulf ports (Appendix G), **Tampa, New Orleans, Houston**, and **Galveston**, have LPOCs from the **Western Central Atlantic** (described above under Atlantic Coast Ports). For Galveston this number is heavily dominated by vessels from the "High Seas" (56 percent, 164/293 [Appendix H]), reflecting in large part back-and-forth traffic of the passenger vessels. For **New Orleans** the LPOCs include vessels from the **Northeast Atlantic** and from the **Mediterranean/Black Sea**. Tampa LPOCs include traffic from the **Northeast Atlantic** as well. All four Gulf ports receive traffic from the **Pacific** and **Indian Oceans**, as well as from the **Mediterranean/Black Sea.**

New Orleans, with 92 LPOCs, has almost twice the number of LPOCs as the highest ranking East Coast port. Houston follows with 84 LPOCs, Tampa, 74, and Galveston with 40.

Pacific Coast Ports: Southern California

San Diego, Long Beach, and **Los Angeles** with LPOCs of 10, 18, and 27 respectively (Appendix G) are predictably dominated by Pacific Rim traffic. LPOCs for San Diego are almost entirely (98 percent) from the **Eastern Central Pacific** (western Mexico and central America, and northwestern South America); 95 percent of this traffic consists of passenger/RoRo vessels running on regular trips between the Mexican west coast and San Diego. LPOCs for Los Angeles also show a strong western Mexico signature (70 percent), with some traffic (18 percent) from the **Northwest Pacific** (primarily Japan, Korea, and China, and Hong Kong). **Long Beach**, adjacent to Los Angeles, shows a distinct and reversed pattern, with the **Northwest Pacific** ranking well (68 percent) above the **Eastern Central Pacific** (28 percent) (this is a reflection of the passenger traffic into Los Angeles). All three ports receive some **Atlantic** traffic; of interest is some direct traffic from the **Great Lakes** arriving in the Port of Los Angeles.

Pacific Coast Ports: Northern California and the Pacific Northwest

Oakland and San Francisco (Appendix G), Portland (Appendix G), and Tacoma-Seattle (Appendix G) are similarly dominated by Pacific Rim traffic. Traffic from either the **Northwest Pacific** or the **Northeast Pacific** dominate at all ports except for Oakland, which shows a small amount of **Western Central Pacific** activity (note the total number of vessels is small, however,

and thus this number is based upon only two vessels). **Northwest Pacific** traffic (primarily Japan and Korea) dominates at Portland. Canadian traffic adds to this pattern strongly in Tacoma and Seattle. All but Oakland record Atlantic traffic. Oakland may of course still *receive* Atlantic ballast water -- container ships arriving in Oakland from the Atlantic coast (and with Atlantic water) will often have an LPOC of San Diego or LA/Long Beach, "hiding" their previous Atlantic history.

Portland and Seattle rank highest in LPOC diversity with 18 and 17 ports, followed by Tacoma (9), San Francisco (7), and Oakland (6).

Alaska

Anchorage (Appendix G) vessel traffic is completely dominated by traffic from Japan and Korea; along with other **Northwest Pacific** ports, these LPOCs account for 94 percent of this port's traffic. These are in large part fishing vessels. A total of 14 LPOCs are recorded for Anchorage in the subsample, including rare Atlantic traffic.

Hawaiian Islands

Honolulu (Appendix G) is similarly dominated by Japanese traffic (64 percent), with total **Northwest Pacific** accounting for 69 percent of all LPOCs. These are primarily fishing vessels. Remaining traffic of appreciable volume comes from the **Eastern Central Pacific** and from the **Southwest Pacific**. Small amounts of traffic come from the **Atlantic Ocean.**

LPOC by FAO Region for Foreign and Domestic Traffic In and With Ballast, and Effects on LPOC Diversity

Subsamples of 288 vessels each were taken from Baltimore, Norfolk, New Orleans, San Francisco, and Oakland, to derive a picture of the impact of *in cargo* vessels from foreign ports on LPOC diversity (on the assumption that most or all of these vessels arrive *with* ballast, or at least with "unpumpable" ballast on board, which, by mixture with newly pumped water and subsequent discharge may still lead to the release of foreign species). In addition, we subsampled these ports to examine some domestic vessel traffic, both in and with ballast.

Appendix G presents both foreign and domestic traffic data. Certain of the figures in Appendix G present percentage data for foreign traffic only (thus the percentages are different than those in the tables), arriving both in and with ballast traffic. The number of LPOCs for foreign-in-ballast ships for these ports may differ from the LPOCs of the same ports as discussed above because foreign-in-ballast here is a subset of the preceding section, but relative LPOC rankings for the two largest ports of calls for each port remain the same for all but Oakland (where, however, the first ranked LPOC remains the same).

Table 4-16 examines the effect of port systems and in cargo vessels from foreign ports on LPOC analysis. While Baltimore and Norfolk share 18 LPOCs, each one a possible source of ballast water, Norfolk receives shipping from 15 LPOCs that Baltimore does not, while Baltimore receives shipping from 17 LPOC that Norfolk does not. The combined arrivals of Baltimore and Norfolk results in the Chesapeake Bay receiving shipping from 50 different LPOCs. The number of LPOCs for each port considered separately would be 35 LPOC (18 common + 17 distinct) for Baltimore and 33 LPOC (18 common + 15 distinct) for Norfolk. While Baltimore and Norfolk

Table 4 - 16

Last Ports of Call (LPOC) by Port Systems: Foreign in Ballast and in Cargo: Effect of "In Cargo" LPOC Diversity on Overall LPOC Diversity (Baltimore/Norfolk and San Francisco/Oakland)

Chesapeake Bay: Baltimore - Norfolk

	BALTIMORE	COMMON BALT/NORF	NORFOLK	Total
FOR. IN BAL.	3	10	4	17
COMMON FOR. IN BAL. & FOR. IN CARGO	6	1	2	9
FOR. IN CARGO	8	7	9	24
Total	17	18	15	50 Grand Total

San Francisco Bay: San Francisco - Oakland

	OAKLAND	COMMON OAK/SAN FRAN	SAN FRAN	Total
FOR. IN BAL.	1	0	0	1
COMMON FOR. IN BAL. & FOR. IN CARGO	0	3	0	3
FOR. IN CARGO	13	1	4	18
Total	14	4	4	22 Grand Total

are two of the major ports in Chesapeake Bay, there are at least ten other District Ports covered by Customs in the Bay area; thus, the actual number of possible LPOCs is likely to be considerably larger than 50.

The number of sources of **acknowledged** ballast (that is, vessels from foreign ports in ballast) entering Chesapeake Bay is 26 (9 in common + 17 distinct) (Table 4-16). The number of distinct **unacknowledged** LPOC's (that is, vessels from foreign ports in cargo) for the two ports considered is 24, 15 of which are unique LPOCs. This increase in LPOCs by adding foreign in cargo traffic expands the potential source regions of nonindigenous species, since many in cargo vessels are also with ballast (see Appendix E for estimated quantities).

For San Francisco - Oakland, the foreign in cargo LPOCs account for 18 of 22 different LPOCs for that port system, as explained above. Unacknowledged ballast here may thus play a particularly significant role. As with Chesapeake Bay, the San Francisco Bay system includes other significant large ports, such as those at Sacramento (a large woodchip exporter) and Stockton, and thus the actual number of LPOCs in the San Francisco Bay system is doubtless much greater.

Domestic traffic for the Atlantic ports of Baltimore and Norfolk comes from the Atlantic region, while New Orleans picks up a small amount of Pacific traffic as well. The amount of Atlantic vessel traffic arriving in San Francisco Bay is difficult to determine, as LPOC data are biased by Atlantic ports "disappearing" from the record when an Atlantic vessel passes through a southern California port, as noted above for Oakland. The importance of the *source of ballast water on board*, as compared to LPOC, is thus particularly underscored by this phenomenon.

How Good an Indicator is LPOC of Actual Source of Ballast Water on Board?

Tables 4-17 and 4-18 present APHIS data for the relationship between LPOC and source of ballast on board (BOB), and for the relationship between the FAO region and BOB. Data are presented as **no ballast on board** (NOBOB), **some ballast on board** (SOBOB), and **all ballast on board** (ALLBOB) from the LPOC (directly or as its FAO region). Table 4-19 combines these data.

For Table 4-17, the total number of vessels (965) does not equal the four subcategories; many other vessel types are included in the 965. For Table 4-18, the total (713) is different from 965 because removed in Table 4-18 are many vessels for which the FAO region could not be reliably identified (that is, vessels that ballasted "at sea").

In the restricted terms of the LPOC itself, the LPOC is a poor predictor of ballast water source (Table 4-19). For 53 percent of all vessels, there is no ballast water on board from the LPOC; this number reaches 66 percent for container ships! Exceptions would occur on some dedicated traffic lines, such as the woodchip bulkers leaving Japanese ports in ballast for Canada, the United States, Tahiti, Australia, and other countries (although with these vessels as well a certain amount of ballast water may come from offshore Japan and from the mid ocean).

When LPOCs are expanded into FAO regions, the relationship is considerably improved, particularly for container ships (SOBOB) and for all ships for ALLBOB. The strongest relationship between LPOC converted to FAO region comes when SOBOB and ALLBOB are combined: 66 percent of all vessels have at least some or all of their water from the LPOC/FAO,

Table 4-17

Relationship between Last Port-of-Call and source of the ballast water carried by vessels entering U.S. ports (where the relationship could be determined from the data).

Vessel Type	N	NOBOB n	NOBOB %	NOBOB LPOC n	NOBOB LPOC %	SOBOB LPOC n	SOBOB LPOC %	ALLBOB LPOC n	ALLBOB LPOC %
All	965	154	16	512	53	168	17	131	14
Container	215	5	02	142	66	59	27	9	04
Bulker	321	40	13	154	48	50	16	77	24
Tanker	179	95	53	47	26	17	10	20	11
General Cargo	83	7	08	54	65	9	11	13	16

Table 4 - 18

Relationship between FAO region of Last Port-of-Call and FAO region of source of the ballast water carried by vessels entering U.S. ports (where the relationship could be determined from the data).

Vessel Type	N	NOBOB n	NOBOB %	NOBOB LPOC n	NOBOB LPOC %	SOBOB LPOC n	SOBOB LPOC %	ALLBOB LPOC n	ALLBOB LPOC %
All	713	155	22	89	12	154	22	316	44
Container	133	5	04	16	12	65	49	47	35
Bulker	242	40	17	23	10	36	15	143	59
Tanker	157	95	61	11	07	9	06	42	27
General Cargo	68	7	10	13	19	9	13	39	57

The following Legend applies to both of the above Tables.

NOBOB: NO Ballast water On Board.
NOBOB LPOC: NO Ballast water On Board is from the Last Port-Of-Call.
SOBOB LPOC: SOme Ballast water On Board is from the Last Port-Of-Call.
ALLBOB LPOC: ALL Ballast water On Board is from the Last Port-Of-Call.

TABLE 4-19

RELATIONSHIP BETWEEN NOBOB, SOBOB, AND ALLBOB and LPOC ONLY and LPOC CONVERTED TO FAO REGION

(Numbers are percentages)

	NOBOB from:		SOBOB from:		ALLBOB from:	
	LPOC	LPOC/FAO	LPOC	LPOC/FAO	LPOC	LPOC/FAO
All vessels:	53	12	17	22	14	44
Containers:	66	12	27	49	4	35
Bulkers:	48	10	16	15	24	59
Tankers:	26	7	10	6	11	27
Gen Cargo:	65	19	11	13	16	57

	SOBOB and ALL BOB from:	
	LPOC	LPOC/FAO
All vessels	31	66
Containers	31	84
Bulkers	40	74
Tankers	21	33
Gen Cargo	27	70

LPOC	Last Port of Call
FAO	UN/Food and Agriculture Organization
NOBOB	No Ballast on Board
SOBOB	Some Ballast on Board
ALLBOB	All Ballast on Board

reaching a high of 84 percent with container ships (but a low of 33 percent for tankers).

LPOC data (from Census TM 385 reports) are the most accessible data now available for possible ballast sources, but these data sets will require specific BOB supplementary source data to permit an understanding of the actual sources of nonindigenous species arriving in U.S. waters. While collapsing LPOCs into regional FAO pictures is useful for a general understanding, these data would fail to identify vessels coming from regions of primary concern ("Global Hot Spots"), nor, as noted, do they provide any fine resolution of source regions.

Chapter 5.

ECOLOGY OF INVASIONS AND THE BALLAST WATER INVASIONS OF THE UNITED STATES

Introduction

Biological invasions in aquatic environments frequently have profound ecological, economic, and social consequences. Not all invasions have striking negative effects. Many invasions appear to have little obvious consequence when considered in any sense, and some invasions have had strong positive economic impacts (such as the edible Japanese littleneck clam *Venerupis philippinarum*, introduced accidentally with oysters, in the Pacific Northwest). However, numerous nonindigenous species have become predators, competitors, and disturbers. Invading phytoplankters can cause toxic and harmful algal blooms, and many invaders are parasites, pathogens, or other disease-causing agents of fish, shellfish, and humans. The past record of invasions with negative impacts sets the stage for vector management. When and why invasions occur and the ability to recognize invaders are an integral part of this management foundation.

Why Invasions Occur When They Do: A Host of Hypotheses

Dramatic global ballast-mediated invasions in the 1980s have sparked a good deal of discussion as to why ballast water would or could play a greater role in the dispersal of nonindigenous species than it had previously. The Great Lakes were invaded by the zebra mussel Dreissena polymorpha and five other species of European freshwater organisms; the U.S. Atlantic coast was invaded by the Japanese crab Hemigrapsus sanguineus; U.S. Pacific coast estuaries were invaded by Chinese and Japanese copepods, amphipods, other crustaceans, and the clam Potamocorbula amurensis; Australia was invaded by Japanese dinoflagellates, and the Black Sea was invaded by American comb jellyfish. Scores of other invasions were reported as well. A global epidemic of phytoplankton blooms is now occurring (Smayda, 1990) and ballast water has played a clear role in some of these events (Baldwin, 1992; Chapman et al., 1993). These intensive patterns of invasion would lead to the prediction that additional invasions are now occurring, and will certainly occur in the future, if the hypothesized mechanism of transport, ballast water and sediments, continues -- that is, if the faucet is not shut off or the leak not significantly reduced in some manner.

However, as Carlton (1992b) has noted, "Predictions of what species will invade, and where and when invasions will occur, remain one of the more elusive aspects of biological invasion science." Why, for example, the zebra mussel successfully colonized Lake St. Clair and Lake Erie about 1986 (to be discovered two years later), remains unknown. Speculations that the zebra mussel was a candidate for introduction to North America have been made every decade since the 1920s. But by May 1988 (one month before the discovery of zebra mussels), and with the apparent failure of the mussel to appear in America, one potential conclusion would have been that the American environment was in some manner inhospitable to the zebra mussel, given the probability that it *had* been transported and released in America on more than one occasion by any of a number of transoceanic dispersal mechanisms.

In Box 5-1 we outline six hypotheses which would seek to explain the appearance of the zebra mussel in North America in the 1980s. In essence, however, these hypotheses *relate to any*

BOX 5-1
WHY DO NEW INVASIONS STILL OCCUR?
(OR, WHY DID THE ZEBRA MUSSEL INVADE NORTH AMERICA IN THE 1980s?)

A number of hypotheses may be set forth in an attempt to explain why new species continue to appear in regions where a transport mechanism (such as ballast water) has existed for many years. The following concepts apply to *any invasion, not just zebra mussels.* The zebra mussel literature, both popular and scientific, has occasionally invoked one or more of the following hypotheses as "fact" or "dogma". In reality, we do not know why the zebra mussel, or any other recent invasion, was successfully introduced when it was, and not earlier. Similarly, we cannot explain why many species have not yet been introduced into North America (see Box 5-2, "Is it Too Late?"). It is important to note that these hypotheses are not mutually exclusive.

1. ***Changes in the Donor Region***
The donor region (for example, western Europe) may change *environmentally* and/or in *species composition.* Extensive efforts to reduce pollution, for example, may improve harbor, river, or port water quality to the point that resident species may experience population increases that would make them more readily available to transport and in turn result in large inoculation sizes. Alternatively, the environment may not change, but a new species invades the region, and interfaces (for the first time) an existing transport mechanism (the "hopping aboard the conveyor belt" hypothesis). An example appears to be the history of the dispersal of the southern Californian crab <u>Pyromaia</u> <u>tuberculata</u> which, once it became established and abundant in San Francisco Bay, appeared in Japan shortly thereafter -- due to dispersal by ships -- from where it was then transported to Australia. Similarly, of course, any new invasion establishes a new potential center of dispersal -- thus the Great Lakes are now *exporters* of zebra mussels, San Francisco Bay is now an *exporter* of Asian clams, and so forth. Jones and Caughley (1992) have added the pertinent example that the worldwide increase in aquaculture may lead to the increased distribution of diseases and parasites -- which, in turn, are transportable by ballast water.

2. ***New Donor Regions***
New commodities from different ports, or newly available ports (ports perhaps earlier restricted from greater international commerce due to political forces), create opportunities for the transportation of species that have not previously been dispersed by one or more human-mediated mechanisms. Alternatively, new ports may make available different genetic stocks of species that have been transported from other regions previously. Both situations may lead to the appearance of novel species. The opening of more international trade between mainland China and North America may be one of the reasons for the appearance of Asian copepods, and the clam <u>Potamocorbula</u> <u>amurensis</u>, in San Francisco and other west coast estuaries.

3. ***Changes in the Recipient Region***
The area being inoculated, regularly or irregularly, by nonindigenous species, may change in one or more ways, thus altering the "resistance" or "susceptibility" of the region to invasions. A number of arguments pertain here: the region may become *less polluted*, thus being more susceptible to invasions by species previously excluded or the region may become *more polluted*, thus being susceptible to invasions by pollution-tolerant species,

particularly as previously present species decline. Examples of the former are often said to be the up-river invasions by shipworms and gribbles, after the establishment of sewage treatment plants, in regions with little or no historical wood borer destruction; examples of the latter include almost all examples of the establishment of new sewer outfalls, and the subsequent elimination of the original biota and its replacement by a suite of species of broader physiological plasticity. Cordell et al. (1992) have suggested that the recent establishment of the Asian calanoid copepod Pseudodiaptomus inopinus in the Columbia River estuary "may have been encouraged by a synergism between increased ballast dumping [see hypothesis 5, below], decrease in maximum flows due to regulation of the river, and the attenuation of extreme low temperatures in the estuary during the last decade." Similarly, Nichols et al. (1990) have suggested that the success of the Asian clam Potamocorbula in invading San Francisco Bay may be related in part to the depression of the native biota as a result of sustained drought. "Global warming" would cause changes in mean temperatures; Mandrak (1989) has related such changes to the potential invasion of the Great Lakes by southern freshwater fish species.

4. ***Invasion Windows in the Recipient Region***
Invasions may occur when the "proper" combination of physical, chemical, biological, and/or ecological variables occur. Johnstone (1986) has thus referred to the concept of "invasion windows", wherein one or more "barriers" to invasion are removed, permitting a successful colonization event. This phenomenon may be relatively independent of the other phenomena noted here, and further invokes a potentially large number of stochastic events.

5. ***Dispersal Vector and thus Inoculation Frequency Changes***
This hypothesis invokes changes in ships and shipping patterns to explain novel invasions. These center around three potential phenomena, any or all of which could lead to an increased rate of inoculation of nonindigenous species:

> *More water is being released*, because there are more ships and/or larger ships. Thus, Hutchings (1992) has noted that the volume of ballast water discharged into Australia "increased dramatically" from the late 1960s and onwards with the advent of bulk cargo carriers. Couper (1983) also noted that since the 1960s a revolution in merchant shipping occurred as containerization reduced time in ports from weeks to days and as bulk carriers and tankers increased vastly in size.

> *Ships are faster than in previous decades*, thus voyages are shorter and survival of entrained species may be better.

> *Ships' ballast tanks are cleaner*, because of the greatly increased number of vessels now transporting water in either segregated or dedicated tanks, as a result of both new international and national laws.

Thus, if more species, and greater numbers of individuals, are being released at greater rates, there is a greater chance of interfacing with changes in the environment (hypothesis 1) or, indeed, "invasion windows" (hypothesis 4). While a good deal of anecdotal evidence appears to be available that more water is being released, that ships are faster, and that ships' ballast tanks are cleaner, no formal studies have been martialed that demonstrate these phenomena in a detailed, quantitative fashion. It may be noted that increased vessel

BOX 5-1 (continued)

speeds could further mean that more ports could be visited in lesser time, meaning that more species could be spread faster.

6. ***Stochastic Population-Inoculation Events***
   Independent of the other phenomena described above, "simple" stochastic events may occur, wherein a rare event occurs and very large numbers of a species are ballasted aboard a vessel. Thus, a single vessel may have ballasted up hundreds of millions of zebra mussel larvae (or indeed "juveniles"), and released most of these in Lake St. Clair and/or western Lake Erie.

There remains the possibility that a certain amount of the apparent increase in ballast-mediated invasions may be independent of invasion ecology and more dependent upon scientists themselves. It is often observed that when attention is called to a phenomenon, more examples quickly are discovered and reported. There further remains the possibility that species are being assigned to ballast water transport without adequate attention to other potential mechanisms -- such as external ship fouling and entrainment, ships' chain lockers and anchors, and semisubmersible exploratory drilling platforms.

invasion. These hypotheses are set against the background question of why species continue to appear long after an invasion corridor with an active transport mechanism has existed. Why, in essence, do not most of the transportable species become transported immediately? Two hypotheses focus on the donor (source) region; two focus on the recipient region, one hypothesis focuses on the mechanism of dispersal, and one on stochastic population-inoculation events. In Box 5-2, we examine a correlated question relative to the utility of undertaking ballast water management relative to the widespread misconception that most invasions may have already occurred, and note examples of future potential invaders.

It is important to emphasize that the successful establishment of a species is rarely related to any one environmental parameter. The life history stage of the colonizer, the chemical and physical nature of the environment, trophic resources, competitors, predators, the levels and ranges of biological and physical disturbance, and a host of other variables in reality mediate invasion events.

Recognizing Invasions: Complexities and Classical Perceptions

All species in a community can be grouped into three categories: native species, non-native species, and cryptogenic species. The following discussion on species origins and history pertains, with possible exceptions, to ***shelf-dwelling (neritic, inshore, shallow-water) organisms found in less than 200 meters depth.*** These include estuarine (brackish-water), marsh harbor, port, lagoon, bay, inlet, sound, and shallow fjord organisms.

Native species are those that have been prehistorically present in the community. Biological invasions (non-native species) include range expansions (natural movements along corridors) (range extensions are the reports of new geographic records, not the expansion itself) and introductions, species transported within historical time by human agencies (Carlton, 1987, 1989). Historical records for most species in most communities are unavailable. In classical biogeography, species with no historical record are considered "native." In fact, many such species are cryptogenic, species neither clearly native nor introduced. All lists of all species in the communities under consideration here should thus be divided into these three categories. With rare exception however, biogeographers and systematists divide species up only into the two categories of "native" or "introduced."

Many marine, brackish, and freshwater organisms are reported as very widely distributed. Some species are considered cosmopolitan, occurring over several oceans and continents and often in many habitats. Other species are considered to be panboreal, pantemperate, or pantropical -- extending in a band or arch throughout latitudes and longitudes of similar temperature. Other species are considered amphioceanic, occurring transoceanically across an ocean, from one continental margin to another (such as "amphiAtlantic" species in the North Atlantic Ocean). Yet other taxa may be considered bitemperate or bipolar, occurring in the northern and southern hemispheres but not in the intervening tropical regions.

Such widespread distributions may arise from three possible causes: (1) the distributions may be natural, having arisen from natural dispersal/isolation processes, (2) the distributions may be human-mediated, having arisen from dispersal by humans, (3) the distributions may be erroneous, the reports arising from the misidentification of two or more species as one species. Widespread distributions may be reported as continuous or patchy. Thus a species may have been

BOX 5-2

IS IT TOO LATE?: FUTURE INVASIONS

One of the most frequent questions and comments that are asked or made relative to the potential for future invasions by ballast water is why, if ballast water has been moved from point "A" to point "B" for a given number of years, all the species that could have been transported and successfully established would not have already done so. Indeed, this may be carried one step further with the observation that "All species that could have been introduced by ballast water would be here by now." Some members of the public and of the scientific community have offered the latter statement.

The continual appearance of new species, believed to be transported by ballast water, argues against the completion of the potential pool of invaders. The six hypotheses outlined in Box 5-1 offer reasons why such new invasions would occur, long after a dispersal mechanism on an invasion corridor has existed. A conclusion is that invasions occur at an unpredictable point along the history of a transport mechanism and corridor.

A useful corollary question does, however, arise from this observation: if no "major" invasions have yet occurred in a given region, despite many years of the existence of a transport mechanism, and despite evidence for the continued release of nonindigenous species, does this mean that the risk of invasions in this region is "lower"? An example would be Chesapeake Bay -- where, while invasions have occurred (see text and Table 5-1), no salt-water invasions of free-living invertebrates have *apparently* occurred at the scale of the zebra mussel in the Great Lakes or of the Asian clam in San Francisco Bay (there have been no formal studies of the biological invasions of the Chesapeake Bay system, and thus it is not possible to be unequivocal in this example). The Chesapeake system receives ballast water from many regions of the world both in the upper bay (Baltimore, Alexandria) and the lower bay (Richmond and the port system of the Hampton Roads region). One answer is that the risk of invasions *may be* lower than in "high invasion systems" (such as the Great Lakes or San Francisco Bay), but this only means that the *number* of successful invasions may be lower -- *not that there is no future risk of invasion of a species with profound potential for ecological, economic, and social disruption.* Local environmental changes (Box 5-1) can alter sites with a previous history of few introductions to sites that are highly susceptible to new invasions.

Thus, as long as a transport mechanism exists -- such as the conveyor belts of ballast water now wrapping around the world -- the potential remains for new invasions. Carlton et al. (1993a) and Carlton (1992b) have considered potential future invasions into North American fresh, brackish, and salt waters. It is critical to emphasize that it is impossible to make a complete list of all potential unwanted invaders from a foreign source, in large part because many species do not express "nuisance" characteristics within their native ranges. As discussed in Box 6-3, this phenomenon is the foundation of the difficulty in the "certification" of ballast water and/or sediments as "free" of one or a limited group of species -- while others may still abound.

It is nevertheless possible to identify a number of species which have invaded other regions and/or are species of ecological or economic concern, which have not yet reached American shores. A *few* examples are as follows:

BOX 5-2 (continued)

The Chinese freshwater mytilid Limnoperna fortunei (Morton, 1977a, 1977b) and the Indian estuarine mytilid Modiolus striatulus (Morton, 1977a, 1977b), both important fouling mollusks, may yet reach North America. Limnoperna was most recently reported as invading Taiwan by Tien-hsi et al. (1987).

The Asian brown alga Undaria pinnatifida, which has newly invaded Australia and New Zealand (Sanderson, 1990; Hay, 1990) and Europe (Floc'h et al., 1991), appears to be a strong candidate for American invasion. (The Japanese brown alga Sargassum muticum, already established on the North American Pacific coast and in Europe (Critchley, 1983), will predictably be introduced to the North American Atlantic coast).

The fouling amphipod crustacean Corophium curvispinum, newly abundant in huge densities (100,000 per square meter) in the Rhine River (van den Brink et al., 1991), is without doubt now being distributed from this "Global Hot Spot" to shores around the world. Carlton et al. (1993a) predict its invasion on the Atlantic coast of North America by ballast water. Its increase in abundance in the Rhine River and thus its potential dispersal to North America relates to invasion hypothesis 1 in Box 5-1.

The small freshwater hydrobiid snail Potamopyrgus antipodarum (= P. jenkinsi), native to New Zealand and introduced to Europe, with densities reported at > 800,000/square meter, is a probable invader of eastern North America (Carlton et al., 1993a). It now occurs in the Middle Snake River system of southern Idaho, but details of the source and mechanism of its introduction there in the 1980s are not known.

The toxic, tropical algae Caulerpa taxifolia, a new invader of the Mediterranean (Meinesz and Hesse, 1991), is a striking candidate for ship dispersal to southern U. S. waters.

The Japanese opossum shrimp (mysid) Neomysis japonica, introduced by ballast water to Australia (Jones, 1991) is predictably already present, but overlooked, in Pacific coast bays and estuaries.

It is not too late for global ballast water management. There are thousands of species on the invasion horizon.

documented at hundreds of locations or from only a few stations around the world. Both distributions are frequently referred to as "cosmopolitan." In this regard, biogeographers further frequently note a complicating phenomenon: the distribution of many species of plants and animals may simply reflect where biologists have sampled (Hutchings et al., 1987; Pollard and Hutchings, 1990, p. 243). Thus, the same species of marine worm found in Japan and Australia (but with no known intervening populations) may reflect either truly disjunct populations (due to (1) or (2)), may not be the same species at all (3), or may actually have a continuous (although incompletely known) distribution from Japan to Australia (with or without tropical interruption).

Carlton and Chapman (in preparation) explore in detail more than 20 biogeographic, historical, mechanistic, ecological, biological, evolutionary and genetic criteria by which to objectively determine whether a species is native, introduced, or cryptogenic, and whether a species' global distribution can be attributed to one or more of the above phenomena and processes.

As a result of these complexities, there can be little doubt that the role of human-mediated dispersal of aquatic organisms has been vastly underestimated. Despite the cryptogenic status of thousands of species, many species whose history, systematics, and/or biogeography are reasonably well known can be recognized as owing their modern day distributions to the movements of vessels around the world since at least the 14th century.

A "classic" pattern of ship-mediated dispersal would be one where a species is widespread along the inshore continental margins of one ocean basin and is also recorded *from a few isolated port systems* in another ocean basin (note that many other disjunct distributional patterns in and of themselves do not necessarily indicate human-mediated dispersal). Seasquirts (ascidians), well-known ship fouling organisms, provide excellent examples. A number of North Atlantic species, for example, have been transported to the Pacific Ocean. Ascidiella aspersa is also known from Australia and New Zealand (Kott, 1985), where it was doubtless introduced by ships at an early date. Ascidiella aspersa has recently (>1985) appeared in southern Massachusetts and Connecticut (J. T. Carlton, unpublished). Ciona intestinalis is now known from a few port systems around the Pacific Ocean (Carlton, 1979a, who corrects earlier misinterpretations of its North American Pacific coast distribution, and demonstrates that it is restricted in the Northeast Pacific to harbors and ports from San Francisco to San Diego), and Molgula manhattensis is present in harbors in Washington, Oregon, California, Japan, and Australia. Such clear disjunct patterns become increasingly obscure as species are reported from scores or hundreds of locations, as might be expected of taxa transported from one ocean to another three or four centuries ago.

The Role of Wars: Shipping Corridors and the Dispersal of Marine Organisms

Wars create altered shipping corridors involving military vessels, vessels pressed into military service, and the merchant marine. These corridors may be novel (distinct from historical trade routes) or simply impose upon older routes much higher levels of transport activity. It is thus not surprising to find that a large number of marine organisms are thought to have been newly introduced co-incidental to wars. The Australian barnacle Elminius modestus appeared in England during World War II (Elton, 1958). Two species of Philippine jellyfish (Cuttress, 1961), the Californian isopod crustacean Paracerceis sculpta (Miller, 1968) and a number of Indo-Pacific crabs (Edmondson, 1951, 1962) were carried to the Hawaiian Islands during World War II. The

Californian salt water fly Ephydra gracilis was collected at Hickam Field, Honolulu, at the end of the war in 1946, an occurrence Wirth (1947) related to the proximity of the Oahu seaplane bases. Cooke (1975) speculated that the presence of many cosmopolitan hydroids at Enewetak Atoll may be due to the "many hundreds of ships and barges that visited in the later part of World War II and during the period of atomic bomb testing".

These examples may reflect only the tip of what remains a largely uninvestigated phenomenon in Pacific Rim biogeography (Carlton, 1987). The Korean-Japanese shrimp Palaemon macrodactylus was discovered in San Francisco Bay shortly after the Korean War (Newman, 1963). A number of western and southwestern Pacific invertebrates appeared in central and southern California harbors during the Vietnam War (1962 -1975); Carlton (1979a) provides a summary. Among these were the Indian Ocean fouling isopod Sphaeroma walkeri, which completed its world voyages by arriving in San Diego Bay, the largest naval port in the western hemisphere, by 1973 (Carlton and Iverson, 1979). Chapman (1988) described the new amphipod species Corophium alienense from San Francisco Bay, where it was first collected in 1973, and concluded (based upon morphological similarities to its nearest relatives) that it was a Vietnamese species. Morton (1980) proposed that the fouling dreissenid mussel Mytilopsis sallei was transported to Hong Kong on boats of Vietnamese refugees. "Normal" military activity may, of course, transport species as well. Sakai (1976) suggested that an individual of the Chesapeake Bay blue crab Callinectes sapidus found near the Yokohama Naval Base in Japan in 1975 may have been introduced in the ballast tanks of submarines arriving from the east coast of the United States. Here, however, normal commercial vessel traffic cannot be excluded.

Ballast Water Invasions of the United States

Given the great difficulties in recognizing which species are in fact invasions, we present here the first checklist for the United States of introduced species whose introduction is believed to be related to ballast water (Table 5-1). Included are species for which ballast water is the **probable** mechanism of introduction (no other mechanism appears plausible at this time) and species for which ballast water is a **possible** mechanism of introduction (*alternative dispersal mechanisms* have been identified; see Table 5-1 for a list of these).

A total of 103 species are identified. Table 5-2 provides a tabular summary of these by region of introduction, origin, and probability of ballast-mediated transport. Twenty-nine species are native to America and have been transported within the United States; of these, 21 are probable ballast water species. Seventy-four species are foreign (not native to the United States). Of these, 16 are found in the Great Lakes. **The number of foreign marine organisms which have been probably and possibly introduced through ballast water is 57 species.**

Regions best studied are the Atlantic and Pacific coasts. The significant influence of the four factors listed below upon all American studies makes it difficult to distinguish if in fact the lack of reports of invasions in the last 20 years on the Gulf, Hawaiian, and Alaskan coasts is due to these influences or to the possibility that there have actually been fewer invasions on those coastlines than in other regions. Of all foreign marine invasions (probable and possible), 35 (61 percent) occur on the Pacific coast; 15 (27 percent) occur on the Atlantic coast.

There can be no doubt that the number of species listed in Table 5-1 is a *significant*

underestimate of the actual number of ballast mediated introductions. This underestimate is related to three important phenomena:

(1) ***Failure to recognize invasions:*** As outlined in the previous section of this part, most systematists and biogeographers within their taxonomic specialty usually make the assumption that a previously undiscovered species is native rather than cryptogenic. Assigning species to the latter category would spur more detailed investigations into the native *versus* introduced status of many species. In other regions (such as the Hawaiian Islands), species may be recognized as not having previously occurred in the region, but their appearance is assigned to natural processes (such as dispersal via ocean currents), often with no investigation of alternative dispersal mechanisms (such as shipping). While some natural processes, such as ENSO (El Nino - Southern Oscillation) events, lead to the appearances of novel species, these frequently do not establish permanent populations.

(2) ***Absence of regional studies by specialists:*** Where specialists have examined the biota carefully, introduced species are often reported. Thus, a relatively large number of introduced gammarid amphipods and copepods are recognized along the Pacific coast, while the literature remains relatively silent for the rest of North America. Similar patterns occur in many other groups.

(3) ***Absence of systematic studies by specialists:*** Major, ecologically important groups of organisms remain virtually unstudied in many shallow water regions of America. Polychaete worms and diatoms, for example, are two of the most abundant groups of organisms found living in ballast water. In striking contrast is the absence of reports (with a few local exceptions) of invasions of marine worms and phytoplankton (including dinoflagellates and diatoms) in U.S. marine and estuarine waters. This failure is due in part to the first factor listed above and in part to the absence of systematic and biogeographic studies in general. Most diatom, dinoflagellate, and other microalgal "blooms" in North American (U.S. and Canadian) waters, the number of which has increased dramatically in the last 10 to 15 years, are rarely related to ballast water inoculations -- or, indeed, this hypothesis is often rejected prior to any thorough analyses (Chapman et al., 1993; J. Chapman, personal communication, 1992). This within-discipline bias can be striking: while more than 150 species of invertebrates, fish, algae, and salt-marsh plants are now known to have invaded the San Francisco Bay system in historical time (Carlton, 1979; Nichols and Pamatmat, 1988), not a single diatom or dinoflagellate species is reported as introduced to the Bay. More generally, the demise of attention to the marine and estuarine biota of American shorelines has greatly increased the probability of invasions being overlooked. Many invasions may thus go undiscovered, unrecognized, or unreported.

As discussed earlier, biases also exist relative to the potential listing of species as introduced which may in fact be native (a conservative approach is to list any such potentially questionable species as cryptogenic). This bias, however, rarely leads to an *overestimate* of introduced species, because of the probability that far more introduced species have (for the four reasons noted above) been overlooked.

TABLE 5-1

AQUATIC ORGANISMS INTRODUCED TO OR WITHIN THE UNITED STATES BY BALLAST WATER AND/OR OTHER MECHANISMS

(Excluding species for which ballast water is neither a possible nor probable dispersal mechanism)

Alternative dispersal mechanisms (ADM):
S = Ships: fouling organisms external (hull) or internal (sea chests, seawater pipes)
DA = Fisheries: accidental release with discarded algae (seaweed) in shellfish packing
COI = Fisheries: accidental release with commercial oyster industry
OC = Ocean or coastal currents
Other codes:
NA = North America
* = North American endemic species, introduced *within* the United States to localities shown
-- = No known alternative mechanism

ATLANTIC COAST			
Species/Common Name	Possible Alternative Dispersal Mechanism	Source	Remarks
Coelenterata			
Hydrozoa (hydroids)			
Maeotias inexpectata	S	Black Sea	
Blackfordia virginica	S	Black Sea?	
Gonionemus vertens	S	Europe	
Moerisia lyonsi	S	Eastern Mediterranean?	
Crustacea			
Cirripedia (barnacles)			
*Balanus subalbidus (Boston)	S	Southern USA	
Cladocera (water fleas)			
Ilyocryptus agilis	---	Europe	Fresh water
Mysidacea (opossum shrimp)			
Praunus flexuosus	---	Europe	
*Mysidopsis almyra (Ches. Bay)	---	Southern USA	
Decapoda (crabs and shrimp)			
Hemigrapsus sanguineus Japanese shore crab	---	Japan	
Mollusca			
Bivalvia (clams, mussels)			
*Rangia cuneata (Hudson River) Wedge clam	---	Southern USA	
Dreissena polymorpha (Hudson R.) Round zebra mussel	---	Great Lakes	Fresh and brackish water

TABLE 5-1 (continued)

Gastropoda (snails, seaslugs)			
Tritonia plebeia Sea slug	---	Europe	
Bryozoa (bryozoans)			
Membranipora membranacea Kelp bryozoan	---	Europe	
Chordata			
Ascidiacea (sea squirts)			
Ascidiella aspersa	S	Europe	
Osteichthyes (fish)			
*Hypsoblennius ionthas (Hudson River) Freckled blenny	---	Southern USA	Not established?
*Gobionellus hastatus (Hudson River) Sharptail goby	---	Southern USA	Not established?
Rhodophyceae (red algae)			
Antithamnion nipponicum	S	Japan/Mediterranean	J. F. Foertch, pers. comm. (1992); Note 1
Polysiphonia breviarticulata	OC/S	Mediterranean/Canary Is.	Also known from Dominica
Dinoflagellida (dinoflagellates)			
*Ptychodiscus brevis	OC	Gulf of Mexico	East coast occurrences should be examined relative to BW traffic
Alexandrium minutum	---	Europe/Mediterranean	
Bacillariophyceae (diatoms)			
*Coscinodiscus wailesii (?)	---	NA Pacific?	Cryptogenic
Raphidophyceae (chloromonads)			
Aureococcus anophagefferens	?	?	"Brown tide" of 1985-1986. Cryptogenic.

TABLE 5-1 (continued)

GREAT LAKES			
Species/Common Name	Possible Alternative Dispersal Mechanism	Source	Remarks
Platyhelminthes (flatworms)			
Turbellaria			
Dugesia polychroa	---	Eurasia	
Annelida			
Oligochaeta (oligochaete worms) (see Note 2)			
Ripestes parasita	---	Eurasia	
Phallodrilus aquaedulcis	---	Eurasia	
Stylodrilus heringianus (?)	---	Europe	
Potamothrix vejdovskyi (?)	---	Europe	
Potamothrix moldaviensis (?)	---	Europe	
Potamothrix bedoti (?)	---	Europe	
Teneridrilus flexus (?)	---	Pacific Ocean?	Cryptogenic
Psammoryctides barbatus	---	Europe	From St. Lawrence R., Quebec; to be expected in Great Lakes
Crustacea			
Cladocera (water fleas)			
Bythotrephes cederstroemi Spiny water flea	---	Europe	
Eubosmina coregoni Water flea	---	Europe	
Copepoda (copepods)			
*?Eurytemora affinis	---	NA Atlantic/Europe	
Amphipoda (amphipods, scuds)			
*Gammarus fasciatus	S	NA Atlantic	
Mollusca			
Bivalvia (clams and mussels)			
Dreissena polymorpha Round zebra mussel	---	Eurasia	
Dreissena sp. Flat zebra mussel ("quagga")	---	Eurasia	
Chordata			
Osteichthyes (fish)			
Neogobius melanostomus Round goby	---	Eurasia	

TABLE 5-1 (continued)

Proterorhinus marmoratus Tubenose goby	---	Eurasia
Gymnocephalus cernuus Ruffe	---	Europe
*Apeltes quadracus Fourspine stickleback	---	NA Atlantic
*Gasterosteus aculeatus Threespine stickleback	---	Great Lakes/NA Atlantic
Bacillariophyceae (diatoms)		
Actinocyclus normanii subsalsa	---	Eurasia
Biddulphia laevis	---	Atlantic?
Cyclotella atomus	---	Atlantic?
Chaetoceros hohnii	---	Atlantic?
Skeletonema potamos	---	Atlantic?
Skeletonema subsalsum	---	Eurasia
Stephanodiscus binderanus	---	Eurasia
Stephanodiscus subtilis	---	Eurasia
Thalassiosira guillardii	---	Atlantic?
Thalassiosira lacustris	---	Atlantic?
Thalassiosira pseudonana	---	Atlantic?
Thalassiosira weissflogii	---	Atlantic?
Diatoma ehrenbergii	---	Atlantic?
Cyclotella criptica	---	Atlantic?
Cyclotella pseudostelligera	---	Atlantic?
Cyclotella woltereki	---	Atlantic?
Chlorophyceae (green algae)		
Nitellopsis obtusa	---	Eurasia
Chrysophyceae (coccolithophorid)		
Hymenomonas roseola	---	Eurasia
Phaeophyceae (brown algae)		
Sphacelaria lacustris	---	Atlantic?
Rhodophyceae (red algae)		
Bangia atropurpurea	S	Atlantic?
Chroodactylon ramosum	---	Atlantic
Not established:		
Crustacea		
Decapoda (crabs and shrimp)		
Eriocheir sinensis Chinese mitten crab	---	Europe

TABLE 5-1 (continued)

Species/Common Name	Possible Alternative Dispersal Mechanism	Source	Remarks
Chordata			
Osteichthyes (fish)			
Platichthys flesus European flounder	---	Europe	

GULF COAST

Species/Common Name	Possible Alternative Dispersal Mechanism	Source	Remarks
Viruses			
Vibrio cholerae 01	---	South America (Pacific)	
Annelida			
Polychaeta (worms)			
Boccardiella ligerica	S	Europe?	
Mollusca			
Bivalvia (clams and mussels)			
Perna perna Edible brown mussel	S	South America	
Mytella charruana Charru mussel	S	South America	Not established?
Dreissena polymorpha Round zebra mussel	---	Eurasia	Expected in Mississippi Delta by 1993
Crustacea			
Copepoda (copepods)			
*Centropages typicus	---	NA Atlantic	

PACIFIC COAST

Species/Common Name	Possible Alternative Dispersal Mechanism	Source	Remarks
Coelenterata			
Hydrozoa (hydroids)			
Cladonema uchidai	S	Japan, China	
Cubozoa (cubomedusae jellyfish)			
Carybdea marsupialis	S	Mediterranean	

TABLE 5-1 (continued)

Scyphozoa (jellyfish)			
Phyllorhiza punctata	S	Indo-Pacific/Hawaii	
Aurelia "aurita"	S	Japan	N. Greenberg, pers. comm. (1992); Note 1
Annelida			
Polychaeta (worms)			
Ophryotrocha labronica	---	Mediterranean	
Boccardiella ligerica	S	Europe?	Fresh and brackish water
*Nereis acuminata	S	NA Atlantic	
Pseudopolydora kempi	S/COI	Japan	
Pseudopolydora paucibranchiata	S/COI	Japan	
Eteone tchangsii (?)	COI	Japan	
Spionidae: undetermined species	---	?	F. Nichols and J. Thompson, pers. comm. (1992); Note 1
Potamilla sp.: undetermined or new	---	?	(as above)
Oligochaeta			
Tubificoides benedii	---	?	Vancouver Harbor, British Columbia; to be expected in US waters
Crustacea			
Copepoda (copepods)			
Limnoithona sinensis	---	China	
Oithona davisae	---	Japan	
Sinocalanus doerrii	---	China	
Pseudodiaptomus marinus	---	Japan	
Pseudodiaptomus inopinus	---	Asia	
Pseudodiaptomus forbesi	---	China	
Cumacea (cumaceans)			
Hemileucon hinumensis	---	Japan	
Mysidacea (opossum shrimp)			
Deltamysis holmquistae	---	Asia?	Note 1
Isopoda (isopods, slaters)			
Eurylana arcuata	S	New Zealand?	
Dynoides dentisinus	S	Asia	
Sphaeroma walkeri	S	Indo-Pacific	
Ianiropsis serricaudis	S	Asia	
Amphipoda (amphipods, scuds)			
*Ampithoe longimana	DA	NA Atlantic	
Corophium alienense	---	Southeast Asia	
Corophium heteroceratum	---	Japan	J. Chapman,pers.comm. 1992
*Gammarus daiberi	---	NA Atlantic	
Aoroid sp.?	---	Asia?	J. Chapman,pers.comm. 1992

TABLE 5-1 (continued)

Decapoda (crabs and shrimp)			
Palaemon macrodactylus Asian shrimp	---	Asia	
*Rhithropanopeus harrisii Atlantic mud crab	COI?	NA Atlantic	
Carcinus maenas Green crab, shore crab	DA?/S?	NA Atlantic?	
Salmoneus gracilipes Snapping shrimp	---	Asia	D. Cadien,pers. comm. 1986
Mollusca			
Bivalvia (clams and mussels)			
Musculista senhousia (southern CA) Japanese mussel	S	Asia and/or N CA	
Theora lubrica Japanese clam	---	Asia, Indo-Pacific	
Potamocorbula amurensis Asian clam	---	Asia (China?)	
Gastropoda (snails and seaslugs)			
Clanculus ater Topsnail	---	Japan	Not established?
Sabia conica Hoofsnail	---	Japan	Not established?
Chordata			
Osteichthyes (fish)			
Tridentiger trigonocephalus Chameleon goby	---	Japan	
Acanthogobius flavimanus Yellowfin goby	---	Japan	
*Lucania parva Rainwater fish	COI?	NA Atlantic	
Bacillariophyceae (diatoms)			
Gonioceros armatus	---	Australia/New Zealand	
Pseudonitzschia australis	---	Asia?/South America?	J. Chapman, pers.comm. (1993)

HAWAIIAN ISLANDS

Species/Common Name	Possible Alternative Dispersal Mechanism	Source	Remarks
Coelenterata			
Scyphozoa (jellyfish)			
Cassiopea mertensii	S	Indo Pacific	

TABLE 5-1 (continued)

Cassiopea medusa	S	Indo Pacific	
Anomalorhiza shawi	S	Indo Pacific	
Phyllorhiza punctata	S	Indo Pacific	
Mastigias sp., cf. M. papua (?)	S	Indo Pacific	
Crustacea			
Copepoda (copepods)			
Pseudodiaptomus marinus	---	Japan	
Mysidacea (mysids)			
Holmesimysis costata	---	Northeastern Pacific	
Chordata			
Osteichthyes (fish)			
Mugiligobius sp.	---	Philippines	J. Randall, pers. comm. (1991); Note 1
Parablennius tysanius	S	Philippines?	

Table notes:

1. Unpublished records (other than those of J. T. Carlton) are cited as personal communications from authorities as shown. Suggestions that the taxon is either *introduced* and/or that *ballast water transport* is the (or a) mechanism of dispersal are, however, made here (with the exception of the amphipods), and not by the authorities shown.

2. Great Lakes **Oligochaeta**: The three Potamothrix and one Stylodrilus species are re-instated here as possible Great Lakes introductions, although omitted from Mills et al. (1993), based upon the remarks of Brinkhurst and Gelder (1991). Teneridrilus flexus, while known only from the Great Lakes, is included here based upon the remarks of Erseus et al. (1990) of the restriction of the genus otherwise to the Pacific basin.

References for documentation of these species available from J. T. Carlton.

TABLE 5-2

TABULAR SUMMARY OF TABLE 5-1: PROBABLE AND POSSIBLE BALLAST WATER INTRODUCTIONS

ADM = Alternative Dispersal Mechanism noted in Table 5-1

	FOREIGN SPECIES *(transported to the USA)*		NATIVE SPECIES *(transported within the USA)*		
Region	Ballast Water Probable	Ballast Water Possible (ADM)	Ballast Water Probable	Ballast Water Possible (ADM)	Total
ATLANTIC COAST	7	8	2	2	19
GREAT LAKES	16	—	17	2	35
GULF COAST	—	2	1	—	3
PACIFIC COAST	21	14	1	4	40
HAWAIIAN COAST	3	6	—	—	9
Total:	45(*)	29 (**) [= 74]	21	8 [= 29]	103 (*, **)

Freshwater Introductions:
Total Foreign/Native Possible and Probable Introductions into Freshwater Communities: 36 (see note 1)
Total Foreign Probable Introductions into Freshwater Communities: 17 (see note 2)

Marine Introductions:
Total Foreign/Native Possible and Probable Introductions into Marine Communities: 67 (see note 3)
Total Foreign Probable and Possible Introductions into Marine Communities: 57 (see note 4)
Total Foreign Probable Introductions into Marine Communities: 28 (see note 5)

Calculations of Totals of Foreign Species:

(*) Total Foreign Probable: Dreissena (Great Lakes and Atlantic) and Phyllorhiza (Hawaii and Pacific) each scored once only

(**) Total Foreign Possible: Boccardiella (Gulf and Pacific) scored once only

Notes:

Note 1.	Freshwater (FW): 35 Great Lakes (GL) species + water flea Ilyocryptus in Chesapeake Bay	= 36
Note 2.	FW Foreign Probable: 16 GL species plus Ilyocryptus (see note 1)	= 17
Note 3.	Marine (M) : 103 total less 36 freshwater	= 67
Note 4.	M Foreign Probable and Possible: 74 less 17 FW foreign probable	= 57
Note 5.	M Foreign Probable: 45 less 17 FW foreign probable	= 28

Taxa in Table 5-1 excluded from above calculations:

Establishment uncertain:	Clanculus, Sabia, Mytella, Hypsoblennius, Gobionellus
Reported only in Canada:	Psammoryctides, Tubificoides
Uncertain status:	Aoroid amphipod, Coscinodiscus, Aureococcus, five Great Lakes oligochaetes
Not yet established (April 1993):	Dreissena polymorpha (Gulf Coast)
Viruses:	Cholera vibrio (Gulf Coast)

Invasions into the Heartland: The National Waterway System

Shipping from domestic and foreign ports can transport nonindigenous organisms not only to coastal seaports but also to inland ports in the National Waterway System (NWS) (Figure 5-1). Much of the NWS includes the Gulf and Atlantic Intracoastal Waterway Systems, and thus many of the seaports discussed in this report. Ocean-going deep-water vessels can, however, penetrate into U.S. waterways other than the Great Lakes. For waters other than the Great Lakes, the inland extent achievable by deep water ocean-going vessels are as follows:

ATLANTIC COAST		
Hudson River	Albany NY	229 km N of New York City
Delaware Bay	Philadelphia PA (Delaware R)	40 km N of Wilmington
Chesapeake Bay	Baltimore MD (Patapsco R)	20 km N of Chesapeake Bay
	Alexandria VA (Potomac R)	11 km S of Washington, D.C.
	Richmond VA (James R)	142 km NE of Hampton Rds
GULF COAST		
Mississippi River	Baton Rouge MS	205 km N of New Orleans
PACIFIC COAST		
San Francisco Bay	Sacramento CA (Sacramento R)	155 km NE of Golden Gate
	Stockton CA (San Joaquin R)	139 km E of Golden Gate
Columbia River	Vancouver WA	164 km E of Pacific coast
	Portland OR (Willamette R)	176 km E of Pacific coast

Freshwater or euryhaline brackish organisms can be transported up river as fouling or ballast water organisms. From these ports commercial barges, ferries and recreational boats can transport nonindigenous species well above areas navigable by deep water vessels. Thus, barge and other vessel traffic can move organisms as far north as St. Paul-Minneapolis on the Mississippi River, as well as to other inland ports up the Missouri, Illinois, Ohio, Cumberland, Tennessee, Tombigbee, Alabama, Arkansas, Black, Red, and Atchafalaya Rivers. Similarly, non-ocean going traffic can move organisms east of Albany up through the New York State Barge Canal, or north and east of Chesapeake Bay through the Susquehanna River.

Many of the ports in the table above are now highly modified urbanized-industrialized environments, with the native biota long since largely displaced. Such environments are often conducive to invasions. Orsi et al. (1983) have noted, for example, that the "Port of Sacramento [CA] is (an) apparently ideal place for the introduction of planktonic copepods as it is situated at the end of a long (38 km) isolated ship channel that receives water only through ship locks."

It is clear that there are numerous portals into the American heartland. While freshwater organisms released in ballast water can gain access to the Great Lakes, the same holds true for organisms released into the freshwater rivers and ports listed above. As "back doors" to the Great Lakes and other inland water bodies, these corridors remain potential conduits for invasions.

What invasions have occurred in these waters? No summaries are available. Some invasions are recognized however. Table 5-3 provides several examples (these species are also listed in Table 5-1, but here we provide more detailed information). In Table 5-3 we list species introduced at the ocean-end of the river or bay system by ballast water; not included are species that were initially introduced into inland waters and which have

Figure 5-1
(from Parkman, 1983)

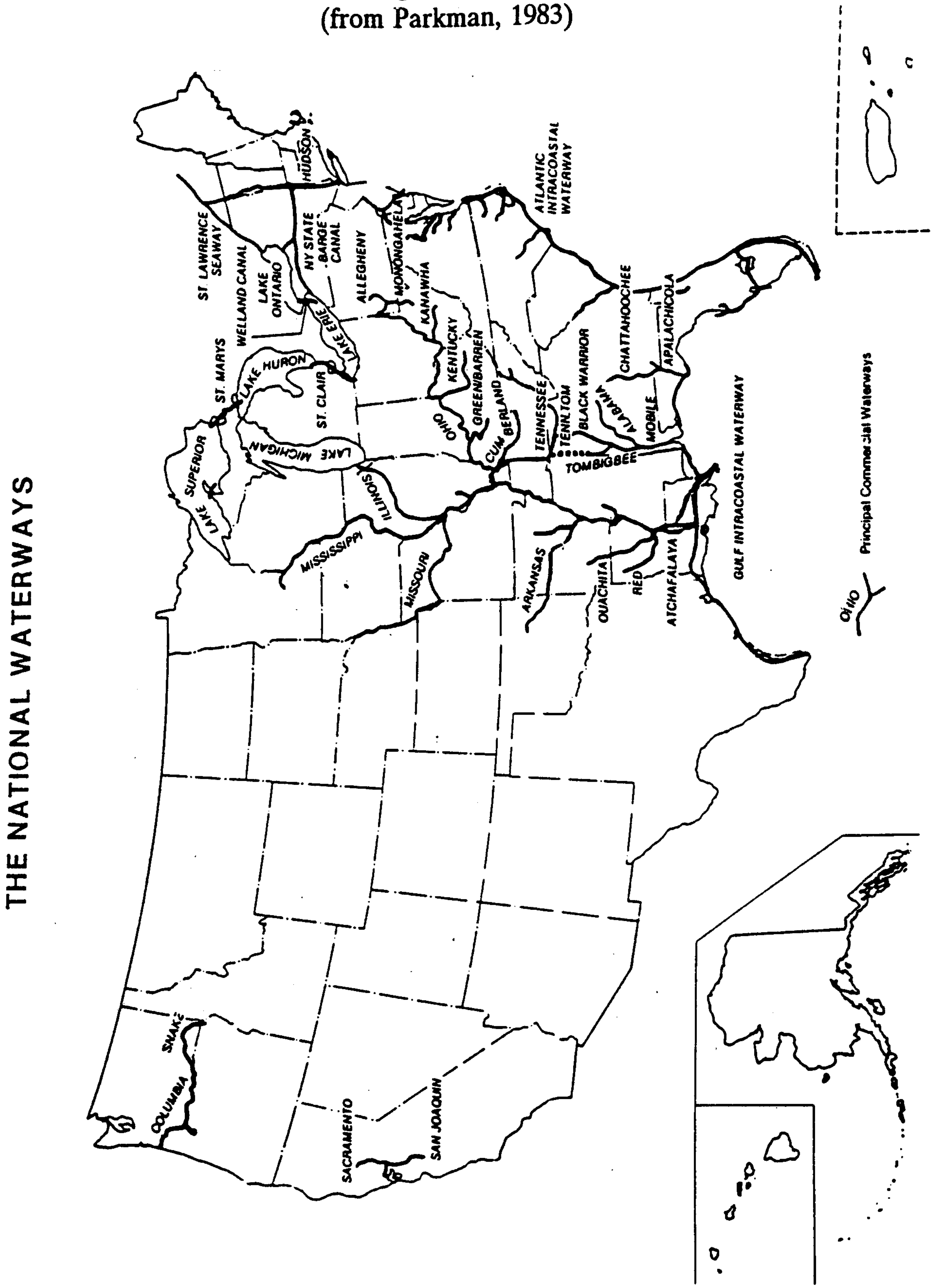


TABLE 5-3

EXAMPLES OF NONINDIGENOUS SPECIES INTRODUCED BY BALLAST WATER INTO THE NATIONAL WATERWAY SYSTEM (OTHER THAN THE GREAT LAKES)

Species	Introduced to (from)	Date first collected and Remarks
Ilyocryptus agilis Water flea	Potomac River (Europe)	1974; nothing appears to be known of the ecology of this species in Chesapeake Bay (Williams, 1978; Carlton, 1985)
Rangia cuneata Wedge clam	Hudson River (southern U.S.)	1988; can occur in dense beds and may thus effect other infaunal benthos (Carlton 1992b; R. Everett, personal communication, 1992)
Pseudodiaptomus inopinus Asian copepod	Columbia River (Asia)	1990; has become one of the three most abundant copepods in the Columbia River estuary (Cordell et al. 1992)
Sinocalanus doerrii Chinese copepod	Sacramento River (China)	1978; Meng and Orsi (1991) have noted that the success of juvenile striped bass may be negatively influenced by the invasion of this copepod and of P. forbesi (below) which appear to be displacing copepods important as striped bass food
Pseudodiaptomus forbesi Chinese copepod	San Joaquin River (China)	1987; in 1988-89, this small copepod crustacean was the most abundant calanoid in the Suisun Bay and Delta of San Francisco Bay (Orsi and Walter, 1991)
Limnoithona sinensis Chinese copepod	San Joaquin River (China)	1979 (Ferrari and Orsi, 1984).

subsequently spread *down* towards the coasts. The copepods Pseudodiaptomus forbesi, Sinocalanus doerrii, and Limnoithona sinensis are known only from or are abundant in the Yangtze River, China. Presumably ballast water from Shanghai, at the Yangtze mouth, is the source of these copepods.

Of further interest are "deeper" invasions into the **Inland Waterway System** (IWS) (Figure 5-2). A series of recent, independent reports, when taken together, suggest that a wave of invasions, arising from the southern U. S. coastline through the Port of New Orleans, has been occurring through the IWS. While the zebra mussel Dreissena polymorpha proceeds south, east, and west from the Great Lakes, a number of native North American species appear to be proceeding northward. Commercial barge traffic and recreational (pleasure) traffic may be responsible for mediating these invasions, but there appear to be no studies on the fouling or ballast biota associated with such vessels, with the exception of U.S. Army Corps of Engineers studies on long-distance dispersal of zebra mussels by barges (Keevin et al., 1993). A thorough study of IWS barge fouling and ballast/bilge organisms would be of extraordinary value at this time, as would an understanding of the changing size and rate of movements of barge traffic over the past decade. In Table 5-4 we provide examples of some of these relatively recent IWS invasions.

TABLE 5-4

EXAMPLES OF RECENT INVASIONS BY NONINDIGENOUS SPECIES INTO THE INLAND WATERWAY SYSTEM

Species	Year first recorded	Records (Source)/Reference
Eurytemora affinis (copepod)	1985	Ohio River (lower Mississippi River, Gulf of Mexico, E/W coast of North America); Bowman and Lewis, 1989).
Corophium lacustre (amphipod)	1988-1990	Tennessee, Mississippi, Arkansas Rivers (Gulf of Mexico); D. Schloesser, personal communication, 1991
Taphromysis louisianae (mysid [possum shrimp])	1981, 1982	Tennessee, Arkansas Rivers (Gulf of Mexico); Garcia-Garza et al., 1992
Mytilopsis leucophaeata (false mussel)	1988	Upper Mississippi River: Madison Co., Illinois (Gulf of Mexico); Koch, 1989; in 1992 in Ohio and Tennessee Rivers (D. MacNeill, D. Marelli, personal communications, 1992).

A 1992 amendment to 16 U.S.C. 4711(b), the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990, establishes regulations by 1994 for the control of ballast water release on the Hudson River north of the George Washington Bridge. This is the only extension of ballast water regulations to the rest of the NWS outside of the Great Lakes.

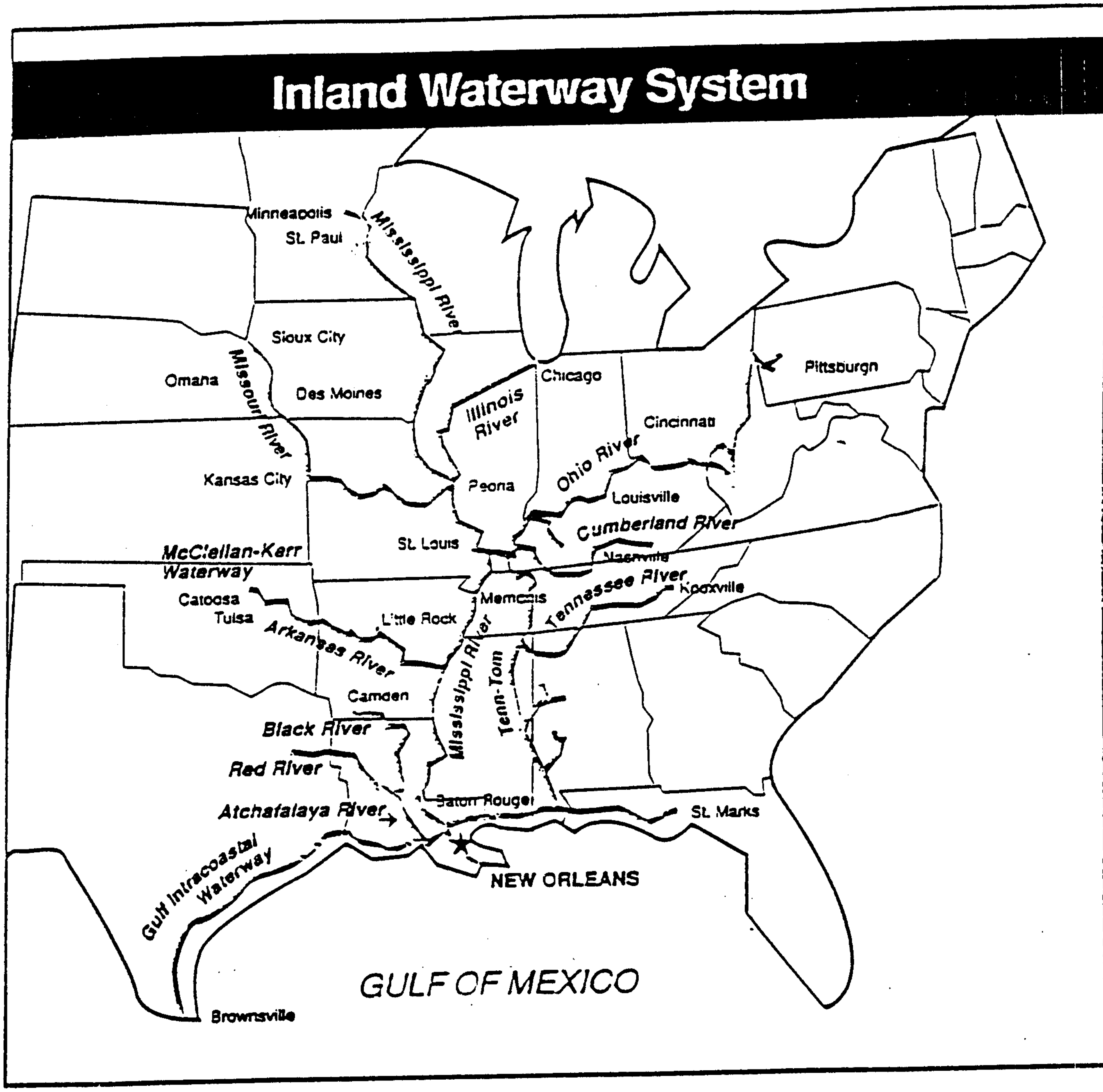


Figure 5 - 2
The Inland Waterway System
(from Port of New Orleans 1991 Annual Directory)

Chapter 6.

ALTERNATIVES FOR CONTROLLING INTRODUCTIONS OF NONINDIGENOUS SPECIES THROUGH SHIPPING

(A) INTRODUCTION OF NONINDIGENOUS SPECIES THROUGH BALLAST WATER AND SEDIMENTS

Scientific investigations on options for controlling of the release of nonindigenous species by ballast water have intensified since the late 1980s following the discovery of the toxic dinoflagellate Gymnodinium catenatum in Tasmania in 1986 and of the zebra mussel Dreissena polymorpha in the Great Lakes in 1988. While other ballast-mediated invasions preceded these introductions, the economic, social, and political impacts of these new exotics precipitated the most extensive concern to date relative to the potential of ballast water and sediments to lead to more invasions in the future. We discuss here the principles and conceptual approaches to ballast management, and review the major control options that have been proposed.

THE PHILOSOPHY OF BALLAST MANAGEMENT

The philosophy of ballast water and sediment management is similar to the basic philosophy of quarantine science in general: ballast management should seek to prevent the introduction of all organisms, ranging from bacteria and viruses to algae, higher plants, invertebrates, fish, and all other entrained life.

An important corollary to this philosophy is that ***no one option or alternative*** is likely to satisfy this management philosophy. It is not appropriate to single out one alternative as "the most" likely or viable -- rather, a synthetic approach, choosing a number of alternatives simultaneously from a broad menu of possibilities, will eventually maximize the strength of ballast management. We discuss this under "Integrated Ballast Management" (IBM) at the end of this section.

CONCEPTUAL APPROACHES TO BALLAST MANAGEMENT

Ballast management has been approached through a variety of avenues by Australian (Jones, 1991; Rigby et al., 1993), Canadian (Smith and Kerr, 1992), Japanese (Ichikawa et al., 1991) and U.S. (Yount, 1991) workers. Each approach serves to underscore the complexity of achieving global ballast management within the coming decades, but also helps to clarify the heterogeneous nature of the issues facing environmental, industrial, and government interests. The extensive and excellent work of Australian scientists on ballast water and sediments, beginning in the 1970s, is particularly to be noted here, in terms of establishing many fundamental aspects of "ballast science" and in leading the world community in investigating control options.

We group these management concepts into four categories: the **voyage approach**, the **vessel approach** (which includes **short term - long term approaches**), the **industry approach**, and the **treatment approach.** These are summarized in Box 6-1.

Voyage Approach: Vessel Transit Sequence

The voyage approach is the primary method used here by which to categorize the total

BOX 6-1
CONCEPTUAL APPROACHES TO BALLAST MANAGEMENT

The Philosophy of Ballast Management:
Ballast water and sediment management should seek to prevent the introduction of all organisms, ranging from bacteria and viruses to algae, higher plants, invertebrates, fish, and all other entrained life.

VOYAGE APPROACH: VESSEL TRANSIT SEQUENCE

Control:

On or Before Departure	--	En Route	--	On Arrival

Based upon the principles:

Prevention of Organism Uptake: do not ballast up organisms that could survive in the target environment	**Prevention of Organism Survival**	**Prevention of Organism Release**: do not release organisms that could survive in the target environment

VESSEL APPROACH

Control for:

"Larger vessels"	[> 40,000 DWT]
"Smaller vessels"	[< 40,000 DWT]

Control for:

Existing Vessels [No modification] **"Short Term Options"**	--	Retrofit Vessels [Redesign and refit] **"Long Term Options"**	--	New Vessels [New design, new construction] **"Long Term Options"**

INDUSTRY APPROACH

Control based upon level of change in Standard Operating Procedures (SOP)

No change to SOP	--	Moderate change to SOP	--	Extensive change to SOP

Control based upon level of change that would alter the industry's position in the global marketplace

No change in marketplace	--	Moderate change in marketplace	--	Extensive change in marketplace

Control based upon level of vessel and human safety

Options unrelated to safety issues	--	Options potentially related to safety issues	--	Options clearly related to safety issues

TREATMENT APPROACH

Control based upon:

TYPE OF TREATMENT:

Biocontrol, mechanical, and preventative options

LOCATION OF TREATMENT:

Extrinsic: Discharge to shore facility or reception vessel

Intrinsic: Actions taken aboard ship

spectrum of suggested control options (Table 6-1). In the voyage approach, the vessel's "life" is viewed as being in three stages:

"On or Before Departure" from the Port of Ballast Water Origin

The port-of-origin, or port of ballast water origin (also known as the "ballast loading port") is not necessarily the "Last Port of Call", and thus the two must be distinguished. Control upon ballasting is based upon the principle of prevention of organism uptake -- that is, that organisms that could survive in the target environment are not boarded into the ballast tanks or ballasted holds.

"En Route" from the Port of Ballast Water Origin

Control when the vessel is ballasted is based upon the principle of prevention of organism survival, that is, organism extermination (also known as "biological sterilization" of the water, and/or active organism removal, by exchange). Control options in this category can commence immediately upon departure or at any point underway, but before arrival at the destination port.

"On Arrival" at the Ballast Discharge Destination Port

Control at the port-of-discharge, or the arrival port (also known as the Port of Call (POC) or Present Port of Call (PPOC)), is undertaken when the intention of the vessel is to discharge some or all its ballast water. This stage is based upon the principle of prevention of organism release -- that is, no organisms are discharged that could survive in the target environment. This definition of principle permits the transport and release of organisms that are judged by the scientific community to be incapable of living in the target environment.

Australian ballast management is defined in terms of four categories (Jones, 1991, p. 37):

(1) Prevention or minimization of the intake of organisms during loading of ballast water.
(2) Removal of organisms prior to discharge of ballast water and sediment.
(3) Non-discharge of ballast water and sediment.
(4) On-shore treatment of ballast water and sediment.

Category (1) corresponds to "On Departure" and Category (2) corresponds to "En Route" options as defined above (for the latter, "removal" includes killing the organisms). Australian categories (3) and (4) correspond to our "On Arrival" options.

Vessel Approach

The vessel approach focuses upon (a) the size of the vessel and/or (b) the distinction between vessels as they now exist, existing vessels as they might be altered or reconstructed, and vessels to be constructed in the future.

Australian work (Jones, 1991) has identified a general division between smaller vessels more likely to be able to exchange in the open ocean and larger vessels less likely to be able to do so. This division occurs at vessels of approximately 40,000 DWT, corresponding to the 44,000 DWT average size of bulk carriers currently in operation transporting woodchips (20,000 to 25,000 metric tons of cargo) from the Pacific Rim (Australia, Canada, the United States, Tahiti,

TABLE 6 - 1

CONTROL OF THE UPTAKE AND RELEASE OF AQUATIC ORGANISMS BY BALLAST WATER AND SEDIMENT: OPTIONS AND ALTERNATIVES

(in order of Vessel Transit Sequence)

I ON OR BEFORE DEPARTURE FROM PORT-OF-BALLAST WATER ORIGIN

Water Supply: Uptake

1. Specialized Shore Facility Provides Treated Salt or Fresh Water
2. Port Provides City Fresh Water

Prevention of Organism Intake: Ballasting Micromanagement

3. Site: Do Not Ballast in "Global Hot Spots"
4. Site: Do Not Ballast Water with High Sediment Loads
5. Site: Do Not Ballast Water in Areas of Sewage Discharge or Known Disease Incidences
6. Site/Time: Do Not Ballast at Certain Sites at Certain Times of Year
7. Site/Time: Do Not Ballast at Night

Prevention of Organism Intake: Mechanical

8. Filtration

Extermination of Organisms Upon Ballasting (Ballast Treatment)

9. Mechanical Agitation
   a. Water Velocity
   b. Water Agitation Mechanisms
10. Altering Water Salinity
    a. Add Fresh Water to Salt Water
    b. Add Salt Water to Fresh Water
11. Optical: Ultraviolet Treatment
12. Acoustics (Sonic): Ultrasonics Treatment

II ON DEPARTURE AND/OR WHILE UNDERWAY (EN ROUTE)

Extermination of Organisms After Ballasting
(while at Port-of-Origin or while underway, but before arrival at destination port)

Active Disinfection (Ballast Treatment):

13. Tank Wall Coatings
14. Chemical Biocides
15. Ozonation
16. Thermal Treatment
17. Electrical Treatment (including microwaves)
18. Oxygen Deprivation
19. Filtration/Ultraviolet/Ultrasonics Underway
20. Altering Water Salinity: Partial Exchange

Passive Disinfection:

21. Increase Length of Voyage
22. Exchange (Deballast/Reballast)
23. Sediment Removal and at Sea Disposal

Deballasting Only

24. Deballast/No Reballasting

TABLE 6-1
(continued)

III **BACK UP ZONES**

25. Exchange or Deballast

IV **ON ARRIVAL AT BALLAST DISCHARGE DESTINATION PORT**

Water Supply: Discharge

26. Shore Facility Receives Treated and Untreated Water

Prevention of Discharge to Environment

27. Discharge to Existing Sewage Treatment Facilities
28. Discharge to Reception Vessel
29. Sediment Removal and Onshore Disposal
30. In situ Extermination of Organisms Upon Arrival (Options 8, 11, 14)

Non-Discharge

31. Non-Discharge of Ballast Water

V **RETURN TO SEA: EXCHANGE WATER**

32. Vessel Returns to Sea and Undertakes Exchange

and elsewhere) to Japan. The effect of ballast exchange on vessels, in terms of structural issues, is addressed at option (22) below.

A second practical categorization of ballast management centers upon the probable implementation of control strategies relative to *existing vessels, retrofit vessels,* or *new vessels.* No structural modifications of any significance would be necessary to implement control strategies for existing vessels; in essence, these are *short term options.* Structural modifications (redesign and refitting), some requiring vessel time in the yard, but others capable of being done while the vessel is underway, would be necessary to implement other control strategies; these are *long term options.* Finally, new vessel design remains one of the most significant promising directions for ballast management into the 21st century. We do not identify "new vessel design" as a control option per se, as new vessel construction is not a strategy in and of itself -- it "only" takes advantage of incorporating ballast management options (as these may become available) in terms of integral vessel engineering rather than retrofitting. While possible new designs may minimize the total quantity of ballast water needed and/or minimize the need to change ballast condition, control methods will still be required for the ballast water that is carried.

Industry Approach

The industry approach is based upon (a) economics and (b) vessel and human safety. In turn, the economic approach is based upon (i) fundamental changes in standard operating procedure and (ii) cost-effective options that would not alter the industry's position in the global market place. We provide a general overview of the "Cost of Change" relative to the economics of ballast management in Box 6-2.

Under the approach of viewing control options based upon the level of change in Standard Operating Procedure (SOP) there are three general possibilities: no change in SOP, a moderate change in SOP, and an extensive change in SOP. A long-term and certain industry direction in shipping has been to reduce crew size rather than expand it. Streamlining, simplifying, automizing and computerizing shipboard procedures has lead and will continue to lead to fewer crew being required, even aboard the largest vessels. Adding ballast water management to the ship's operational protocols may mean at one extreme the *addition* of at least one additional crew member.

Quantifying "SOP change" is difficult. Discussions with industry personnel identify a desire to minimize the implementation of permanent new operating procedures aboard vessels in favor of the one-time, immediately higher capital cost of vessel retrofit for the installation of biocidal technology. "Change" is thus measured in terms of the investment of time and money into crew training and the subsequent time (hours/week) devoted to on-line, continual, ballast management. A moderate change in SOP would be minimal crew devotion; an extensive change in SOP would be extended crew time or new crew devoted to ballast management. Because of the variables involved (including most of the 21 variables listed in Box 6-2), no further elaboration of SOP change is possible at this time.

Related to changes in SOP would be more extended economic costs which would potentially alter the shipping industry's position in the global marketplace as cost-effective transporters of commercial products. Ballast management procedures and/or technologies could lead to increased shipping costs which could translate into increased costs of transported cargoes. Depending on vessel type, certain control options could lead to "down-time" in terms of cargo

BOX 6-2

THE COST OF CHANGE: THE ECONOMICS OF BALLAST WATER MANAGEMENT

Previous work in Canada, Australia, and the United States has attempted to determine exact costs for ballast water management options and controls. We review some of these potential costs at the appropriate sections. ***The overall economic bases for most options are typically in the order of $1000s to $100,000s per vessel*** (these range from continuing operation costs to one-time refits for biocidal technology). We have not attempted to identify full exact costs for any control option, due to the vast variation in the world merchant fleet, which would make estimates unreliable and unrealistic, and therefore potentially misleading. Such estimates have in the past been based upon the concept of the "average volume of ballast water" in the "average ship," but the existing ranges of vessel capacities and types effectively mitigate against such generalizations when they are used for cost estimates. It is more critical to understand the nature and range of the variables involved. These include:

1. Vessel type
2. Vessel size versus ballast water capacity versus refit costs
3. Vessel age versus refit practicability
4. Vessel speed
5. Diversity and variability of ballast tanks
6. Diversity and variability of holds used for ballast water
7. Diversity and variability of ballast pump capacity
8. Ballast pump age and efficiency
9. Costs of shipyard service in domestic versus foreign shipyards
10. Costs of crew training for ballast management
11. Costs of electricity for ballast pumps
12. Costs of crew time, crew fatigue, and/or additional crew, relative to frequency of need to employ ballast management (frequency of exchange, of sediment management, of use of "high" technologies once a vessel is retrofitted: all of these (and other) phenomena will vary by vessel type, size, commercial trade routes, etc.)
13. Administrative and record keeping costs aboard vessel
14. Administrative and record keeping costs in shoreside company offices
15. Inspection, monitoring, and administrative costs to government monitoring agencies
16. Initial equipment costs (for filtration, UV, etc., equipment)
17. Maintenance costs for ballast control equipment
18. Equipment lifetime
19. Changing costs of technology with costs to be determined based upon projected dollar values five years from the study date
20. Costs of delays in port arrivals and departures and delays in cargo handling
21. The translational costs of the above to the increased costs of shipping overall and thus the passed-on increased costs of raw materials

loading or discharge; other control options, under the full weight of quarantine management, could lead to some vessels being unable to complete their ballast leg or cargo leg because of an inability to leave or alter a Restricted or Prohibited quarantine status (see "Integrated Ballast Management," below).

All countries considering ballast management and involved in extended IMO discussions over the past five years have recognized the importance of the fundamental issues of human and vessel safety. While a simple dichotomy between "safe" and "unsafe" control options is usually not possible, several options are far less promising or appealing because of safety issues, even if they would be biologically effective. These are discussed at the appropriate options.

Treatment Approach

Control options may be grouped by one or more methods of treatment, either by type (biocidal, mechanical, and preventative) or by location. *Extrinsic* treatment options are those involving a shore facility or lighter vessel; *intrinsic* treatment options refer to actions taken aboard the ship.

Taken in a holistic framework, we review at the end of this chapter all of these approaches and further group all options as either more likely to be pursued (and pursuable) or less likely to be pursued.

Options Not Listed in Table 6-1

*** Do Not Use Ballast**

The use of ballast is a sufficiently integral part of the vessel that it is unlikely to be "designed out" in general for ships of the future (L. Martinez, personal communication, 1992).

*** Minimize Need**

Changes in cargo type, availability, and loading practices to maximize the vessel's cargo load can theoretically minimize the need for ballast water. Localized, cargo-specific cooperative efforts in this regard are conceivable, but are unlikely to lead to national or international initiatives at this time.

*** Certification of "Nonindigenous Species-Free" Status**

This concept is discussed at length in Box 6-3.

*** New Vessel Design**

As discussed above, new vessel design takes advantage of other identified options rather than being an option in and of itself.

*** Ballast Tax**

A tax on ballast water, prorated by arrival volume, and perhaps with deduction allowances based on exchange volumes, could raise revenue to permit control option studies and implementation programs. Revenue generation is not, however, a ballast water alternative in terms of biological control *per se*.

*** Desiccation**

Fouling organisms may settle on the inside of ballast tanks and holds. The only known

observations are the settlement of barnacles (Balanus sp.) and campanulariid hydroids on the walls of ballasted cargo holds of woodchip bulk carriers (Carlton and Geller, 1993). These organisms would have been ballasted as meroplankton (that is, in their planktonic larval stages -- nauplii and/or cyprids for the barnacles, and planulae and/or medusae for the hydroids), settled, and grown sometime within the 13 days between ballasting in Japan and arrival in Oregon. Upon arrival at the discharge port, the water is automatically deballasted as part of standard operating procedures, exposing the organisms to air and thus death through desiccation (as well as mechanical abrasion through cargo loading). This phenomenon is sufficiently unique, and control is an automatic result of a standard shipboard procedure, that we do not list it in Table 6-1.

*** Supersaturation of Water**

The induction of supersaturation of atmospheric gases (such as nitrogen) in the ballast water stream (by using venturi or other systems) to form gas bubbles that might be taken into an entrained organism's tissue and blood (in order to induce "the bends") is not listed in Table 6-1. The formation of gas bubbles in an entrained organism depends in large part not on the saturation but on the *pressure levels and changes* achieved. As such, the volume of water, the high flow rates, and the very short time (seconds) that the water would be subjected to saturation, and the absence of sufficient pressure gradients, make this an unlikely option.

Criteria for Analysis of Options and Alternatives

A number of investigators have identified and listed a series of "criteria" by which potential control measures could be studied, evaluated and analyzed. These include but are not limited to the following; under some of these we list other criteria which are at times elevated to separate measures:

Human Safety
Vessel Safety
Costs
Biological Effectiveness (Efficacy) in Removing or Killing Organisms
    (sometimes listed under "practicality"; described by Hutchings (1992) as "the efficiency of elimination").
Shipboard Operational (Technical) Reality: Feasibilities and Practicabilities
    includes need for physical (structural) changes aboard vessels, simplicity of approach, ballast system accessibility, and maintenance of treatment equipment (Operational Reality is sometimes listed under "practicality")
Post-Implementation Monitoring and Assessment
Environmental Impacts (Acceptability)
    includes overboard disposal of chemicals, heated water, and so forth, and disposal of filtrates, sediments, and other materials generated by various treatments

We discuss these (and on occasion more minor criteria) as appropriate in the options below. Because so little is known -- in qualitative, quantitative, or experimental terms -- for most of the alternatives discussed here, strict quantitative rankings (weighted evaluations) of control alternatives based upon these criteria are of little value at this time in providing management direction.

BOX 6-3

ON "BIOLOGICAL CERTIFICATION" AS A CONTROL OPTION

Formal certification of ballast as "free" of a target species has been proposed for ballast management (e.g., IMO/MEPC Resolution 50/31 (1991), section 7.3.16). Certification could take several forms, of which the following are examples:

(a) Certification that the **site** at which ballast was taken up was free of a given species.

(b) Certification that the **water and sediments as actually ballasted** by a given vessel at a given site are free of a given species.

(c) Certification that the **site was not at or within a given distance of a sewage outfall.**

(d) Certification that the ballast **site was not the location of a current human disease outbreak** (such as cholera).

(e) Certification that the ballast **site was not a site of active dredging.**

We have not identified certification as a separate option because it interfaces and overlaps with a broad variety of control possibilities, especially relative to ballast micromanagement. In addition, a number of critical problems are attendant upon certification programs. These include:

(1) Certification that the vessel's ballast water originated from a region "free" of a given taxon (such as toxic dinoflagellates) would require the establishment in the donor country of a rigorous scientific program. As discussed elsewhere, analysis of one or two water or mud samples (secured by ship personnel, port authorities, or others) and submitted to an analytical laboratory would be unacceptable as the basis of certification (in the same sense that a single sample of ballast tank sediments in an arriving ship would be unacceptable). A minimum number of replicated samples (usually three or more), collected with the proper equipment, and representing a variety of sites and bottom types would be required at all of the country's international departure ports. A permanent program of monthly sampling would be required to establish the continued absence of target species (which could be introduced by inbound ships at any time). Resident taxonomic expertise would be required to identify dinoflagellate cysts, other phytoplankton, and a potentially wide variety of other organisms of actual or potential concern, taxonomic expertise absent in most countries and declining in those countries with such expertise at this time. In essence, dedicated certification labs and full-time certification teams would be required.

(2) Certification in the above senses *is potentially counter to the foundation philosophy of ballast management*, which as defined here, is to seek to control all potential biological invasions, ranging from bacteria and viruses to plants and animals. Thus, the possible absence of any one taxon (species), or a few pre-identified species of concern, in arriving ballast does not

necessarily prevent invasions of many other species. Hutchings (1992) has noted that "it is hoped that if the uptake of [certain] organisms can be restricted, then by default the uptake of other harmful organisms will also be restricted." However, water "certified" as "free" of dinoflagellate cysts (for example) may still contain scores of other planktonic and benthic species due to the very process of ballasting. A complete list of all potential "unwanted" or "harmful" invaders from a foreign source is not possible to make, as many species do not express "nuisance" characteristics within their native range. The concept that water is "free" of a target species may lead to the relaxation of concern about other species in the ballast. Thus, a ship certified as "free" of a particular dinoflagellate may have abundant clam larvae. Such larvae would generally be unidentifiable without laboratory culture work requiring days if not weeks. Even if identified, the species might not be on a pre-identified "bad" list. Such would have been the case with a vessel carrying the larvae of the Asian clam Potamocorbula amurensis into San Francisco Bay.

(3) Certification would be difficult for certain types of vessels with frequent ballasting-deballasting behavior. Container vessels typically ballast and deballast several hundred tons of water at each port, often accompanied by low port residency times.

A Global Hot Spot Program (GHP), a non-certification program, is proposed, building upon international and national organizations now in place. GHP would aid shipping authorities at both the present port of call and the next port of call **to be aware of ongoing biological events in coastal waters**, and avoid ballasting, or initiate post-arrival ballast sampling, respectively. Avoidance of Global Hot Spots does not certify a ship as being in a Permitted State, but takes advantage of another step in integrated ballast management (IBM).

CONTROL OF THE UPTAKE AND RELEASE OF AQUATIC ORGANISMS BY BALLAST WATER AND SEDIMENT: OPTIONS AND ALTERNATIVES

(in order of Vessel Transit Sequence)

I ON OR BEFORE DEPARTURE FROM PORT-OF-ORIGIN

1. Specialized Shore Facility Provides Treated Salt or Fresh Water

This technologically simple and appealing option invokes the use of pre-treated fresh or salt water which would be supplied on demand to vessels in port. The same facilities would be prepared to receive untreated water, and either treat the water for resupply as sterilized water or sterilize the received water and dispose of it (option 26). Essentially, this option would require an industrial infrastructure potentially costing hundreds of millions of dollars that does not currently exist: a ballast water treatment industry, including tank farms with advanced water sterilization facilities, a network of underground hard piping to feed to piers throughout the harbor, or separate parent facilities throughout large port systems such as Chesapeake Bay or San Francisco Bay, thousands of trained personnel employed nationally, and interfacing equipment aboard vessels of all nations to receive such water. A daunting administrative framework would be required to support such an industry. The comparatively few ballast facilities now treating tanker "oily ballast" can only be minimally compared to a ballast water supply and treatment industry on a national scale.

We conclude this is not an option to be immediately pursued. Ironically, the roots of this concept are found in an industry that did in large part operate successfully for many years, but when there were far fewer, smaller vessels moving at slower speeds. In the 19th and earlier centuries, large ports had ballastmasters who oversaw the uptake and disposal of solid (rock, sand, etc.) ballast, and in countries throughout the world ships would purchase ballast sand and rock accordingly.

2. Port Provides City Fresh Water

This option is distinguished from Option 1 because it requires no specialized shore facility. Under this option, a vessel would ballast using city fresh water. Direct hook-up dockside (to city water mains, through fire hydrants or other standard procedures) or water made available by lighter would be two boarding options. The clear advantage of this option is that city fresh water should be, with the exception of some bacteria, essentially abiotic (and with the further exception of rare cases where city water filtration systems fail and permit even macroscopic organisms to come through).

A vessel (a RoRo, U. S. flag, DWT 18202 MT, BWCAP 6164 MT) was boarded in Anchorage which was in the practice of obtaining small amounts of fresh water as ballast from the two cities it served, Tacoma WA and Anchorage AK. Ballast was taken on by city water pressure (requiring 6-7 hours in Tacoma and 1-2 hours in Anchorage, for a little over 150MT (about 40,000 gallons)). Salt water ballast was never used aboard this vessel. The Port of Anchorage supplied 30 meters (100 feet) of 6 cm (2.5 inch) diameter fire hose with standard fire hose couplings (and two one-way valves to prevent backflow). In 1992 the hook-up charge is included in the $35 fee for the first 1,000 gallons; additional water is charged at $1.98 per 1000 gallons (taking on 1000 MT (264,000 gallons) would therefore cost about $554). Each additional 1000 MT would cost about $523.

This option would appear to be particularly useful for vessels on defined regional routes serving a few cities, where specific arrangements could be made with the port authorities involved. For many vessels, however, ballast water is required under a variety of circumstances at sea when no freshwater sources are available. In addition, cities in arid regions, or under drought conditions, would be unlikely to be able to regularly supply the volumes of ballast water to be required.

Prevention of Organism Intake: Ballasting Micromanagement

Potentially effective techniques to reduce the probability of uptake and subsequent discharge of certain exotic species (either specific species or general categories, such as dinoflagellates) are those involving ballasting micromanagement in time and space. Whether these are "simple" techniques or not depends on the ability of the vessel to ballast at an alternate time or site without significant new costs. For all of the following -- options 3 through 7 -- ballasting micromanagement does *not* reduce the need for exchange of water or for the use of other eventual techniques (such as microfiltration). Ballasting micromanagement enhances the probability of not boarding certain species or suites of species, adding to the overall efficacy of ballast control.

3. **Do Not Ballast in "Global Hot Spots"**

The foundation of a **Global Hot Spot Program (GHP)** has been implemented in both Australian guidelines and in international guidelines set forth by the IMO's Marine Environment Protection Committee (MEPC) Resolution 50(31) [1991], sections 5.7 and 6.1.

IMO guidelines urge vessel masters to avoid ballasting in regions known to contain "local outbreaks of infectious diseases or water-borne organisms," or known for "the existence of problem species, including local outbreaks of phytoplankton blooms," and to undertake ballast practices that would minimize the uptake of "the cysts of unwanted aquatic organisms and pathogens." Section 6.1 of the IMO Resolution concludes by emphasizing that "Areas where there is a known outbreak of diseases, communicable through ballast water, or in which phytoplankton blooms are occurring, should be avoided wherever practicable as a source of ballast." Hallegraeff and Bolch (1992) further identify the need to avoid ballasting during toxic phytoplankton blooms.

These steps are fundamental and useful, but have the danger of providing a sense to the mariner and the rest of the shipping community that water "free" of these organisms is relatively "safer" or (IMO Resolution 50(31):6.1) "clean." As discussed in Box 6-3, fundamental ballast management philosophy argues for the potential control of the importation and release of all living organisms.

The "Global Hot Spot Program" proposed here is a non-certification program. The Program's purpose is to provide an advisory network that would permit the international shipping community to be made aware of regions where taking ballast water up was not advised. The goal of the GHP would be to significantly expand the size of the network and the species of concern over the limited version of this concept, which is not formalized as an organized Program, by the IMO in its international guidelines for ballast management. Section 5.7 asks Member States to notify the IMO "of any local outbreaks of infectious diseases or water-borne organisms, that have

been identified as a cause of concern to health and environmental authorities in other countries." IMO would then relay this information to all Member States and to non-governmental organizations, such as national shipping federations and agent associations. The end of Section 5.7 includes "local outbreaks of phytoplankton blooms" in the notification pathway.

The GHP differs from the IMO program in (1) being a global advisory network, to include non-Member States of IMO, and (2) expanding the concern for prohibited areas to ecologically significant species (definitions would need to be established) as well as species implicated in human health concerns (such as infectious diseases or toxic phytoplankton blooms).

The GHP would consist of a cooperative network of maritime, human health, and marine environmental organizations. These organizations would include the IMO, the International Chamber of Shipping (ICS), the UN Food and Agricultural Organization (FAO) and the World Health Organization (WHO), the Pan American Health Organization (PAHO), and the International Council for the Exploration of the Sea (ICES) and its new Pacific counterpart (PICES). Three central offices could be established: Eurasia-Africa, Indian Ocean-Indo Pacific-Australasia, and the Americas. IM0 and non-IMO states would provide to the network data, derived from their national phytoplankton and health authorities, on harmful algal blooms (HAB) and derivatives toxic to humans, including paralytic shellfish poison (PSP), diarrhetic shellfish poison (DSP), amnesic shellfish poison (ASP), and neurological shellfish poison (NSP). States would *also* provide to the GHP information on unusual abundances of all other species (examples are given in Table 6-2), based upon data derived from their national marine biological and ecological authorities.

Initial mechanisms for a GHP network are in place. The Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) initiated an international "Harmful Algal News" newsletter in February 1992, focusing on toxic algae and algal blooms. A "Red Tide Newsletter" has been available since 1987. A revised "International Directory of Experts in Toxic and Harmful Algal Blooms and their Impact on Fisheries and Public Health" is in preparation by NOAA/NMFS (*Harmful Algal News*, 1:4). Precedents for international advisories also exist: a well-known example is Norway's 1988 alert (issued through the ICS) about the presence of a harmful alga in their waters (Figure 6-1).

Problems associated with the establishment of a GHP include the current lack of monitoring programs or technical experts in many states. International mandates, as through FAO, WHO, or ICES, may aid in the political arena as arguments for the need to establish such programs where they do not exist. Additional problems include the inevitable lack of agreement as to what would constitute a species of "ecological concern" to be reported to the GHP. While a conservative approach would be to report all increases in abundance of any local species, this approach is unlikely to encourage reporting by cooperating countries. It is important to emphasize that the existence of a GHP does not imply that such a network would prevent the introduction of nonindigenous species, nor does it imply that identifying newly abundant fouling, benthic, planktonic, or other species suggests that these are more likely to invade than "background" species in the same communities (thus, while there are reports of the notable increase of the Japanese clam Theora lubrica in the Inland Sea of Japan -- followed by its appearance in San Francisco Bay where a large amount of water from that region is released (Carlton, 1992b) -- there are no reports of the increase in abundance of the clam Potamocorbula amurensis in Asia prior to its appearance in San Francisco Bay -- nor, indeed, may it have become more abundant than usual.

TABLE 6-2

EXAMPLES OF GLOBAL HOT SPOTS:

POPULATION ERUPTIONS IN COASTAL WATERS OF THE WORLD IN THE 1980s OF NONINDIGENOUS SPECIES (OTHER THAN OF HARMFUL ALGAE (TOXIC PHYTOPLANKTON) OR HUMAN PATHOGENS)

Species (Native to)	New Location	Reference
Comb Jelly Mnemiopsis leidyi (U.S. Atlantic coast)	Russia: Black Sea	Vinogradov et al., 1989; Shushkina and Musayeva, 1990
Moon Jelly Aurelia "aurita" (Japan?)	California: San Francisco Bay	N. Greenberg, personal communication, 1992
Tube-Building Amphipod Corophium curvispinum (Black and Caspian Seas)	Netherlands and Germany: Rhine River	van den Brink et al., 1991
Toxic Tropical Seaweed Caulerpa taxifolia (Red Sea and southern waters)	Northwestern Mediterranean Sea	Meinesz and Hesse, 1991
European Seasquirt Ascidiella aspersa (Europe)	Southern New England	Herein: see Table 3-3
Spiny Water Flea Bythotrephes cederstroemi (Europe)	Great Lakes	Mills et al., 1993
Zebra Mussels Dreissena polymorpha and Dreissena sp. (Europe)	Great Lakes	Nalepa and Schloesser, 1992
Ruffe Gymnocephalus cernuus (Europe)	Great Lakes	Mills et al., 1993

Figure 6 - 1

INTERNATIONAL CHAMBER OF SHIPPING

30-32 ST. MARY AXE. LONDON EC3A 8ET

ICS/53/3
TO: ALL ICS MEMBERS

1st June 1988
ICS(88)34

Dear Sir,

DISCHARGE OF BALLAST WATER LOADED IN ALGAE (CHRYSOCHROMULINA POLYEPIS) INFESTED WATER

The Secretariat has been informed by the Norwegian Shipowners' Association that an algae belt, which is highly dangerous to all other marine life, has infested the waters of the Kattegat and Skagerrak, and is extending along the Norwegian coast up to Haugesund.

It is understood that the present ecological and climatic conditions are very favourable to the growth of the algae, and that the high concentration of algae in the water is presenting a most serious threat to marine life, including the fish farming industry in the area. Press reports are even referring to the problem as "another Chernobyl"

As a precaution against spreading the infestation, the Norwegian State Pollution Control Authorities have recommended that all ships which take on water ballast inside the infested waters should only discharge or change such ballast when in the open sea where the conditions are unlikely to be favourable to the survival of the algae. This precaution will thus contribute considerably towards preventing the spread of algae to uninfested waters, estuaries and harbours.

There is no doubt about the potentially serious consequences of this problem and member associations are requested to draw the foregoing to the attention of any members whose vessels may trade to Northern Europe as a matter or urgency.

Yours faithfully,

J.C.S. Horrocks
Secretary General

Telephone: International +44 1 283 2922
National 01 283 2922

Telex: 884008
Facsimile: +44 1 626 8135

Nevertheless, GHP would aid all authorities at ports-of-call to be aware of ongoing biological events at an unprecedented scale of communication. GHP is another step in integrated ballast management (IBM). A GHP program in place would likely have prevented the transportation of cholera viruses from South America to Mobile Bay, Alabama; it may have prevented the introduction of zebra mussels to the Great Lakes (whose introduction would have been prevented by open ocean ballast water exchange), and it may prevent the future introduction of Corophium curvispinum by aggressive management of the movement of Rhine River water. Similarly, a GHP would serve to advise all countries of the problems of importing ballast water to their countries from the Great Lakes.

4. Do Not Ballast in Regions of High Sediment Loads

This option is a corollary of option (2), but does not identify specific organisms of concern nor specific regions. As such, regions of high sediment loads (due to upriver position, storm runoff, dredging activities, etc.) would not be reported within the GHP (above). IMO and Australian guidelines contain similar advice. As discussed earlier, some vessels already undertake sediment management programs for reasons independent of the prevention of the uptake and release of nonindigenous species, and a more industry-wide application of these procedures is a high-profile and pursuable ballast management option.

A suggestion (G. Ryan, personal communication, 1992) that an attempt be made to take on ballast higher in the water column, or even at the surface, to minimize suspended sediment intake, may be applicable to those vessels that have, or could be refit to have, high suction bays. The usefulness of this approach would depend upon the specific sites involved and the stratification in the water column of the sediment loads. This concept may also be applicable to reducing the intake of organisms found lower in the water column (although, conversely, it could *increase* the uptake of organisms found in the high water column).

IMO/MEPC guidelines (Resolution 50/13 (1992), section 9.2) note, relative to changes in ship design, that "subdivision of tanks, piping arrangements, and pumping procedures should be designed and constructed to minimize uptake and accumulation of sediment in ballast tanks."

5. Do Not Ballast Water in Areas of Sewer Discharge or Known Disease Incidences

This option requires vessels to establish the presence of disease outbreaks and their proximity to untreated or treated water being discharged from sewage treatment plants, and act accordingly relative to ballast water uptake. Of particular concern is the potential transport of human pathogens. Two matters are of concern here:

(a) *The level of treatment:* The plant may be primary, secondary, or tertiary, with increasing or decreasing (depending upon the operation) water quality. In cities with raw sewage discharge, the uptake of ballast water would be strongly contraindicated.

(b) *Altered species composition:* Opportunistic, colonizing species are often the most abundant at sewage discharges; if taken up in ballast water, these species are high profile candidates as potential invaders.

We have observed ballast water taken aboard a research vessel in St. John's,

Newfoundland, approximately 100 meters down current from a sewage treatment facility (J. T. Carlton, personal observation). This water had dense numbers of capitellid polychaete (worm) larvae, which were, in turn, ballasted into the ship. Capitellid worms (particularly species in the genus Capitella) are often strongly associated with enriched organic sites.

6. Do Not Ballast at Certain Sites at Certain Times of the Year

This option is inspired by the comment, "use of water on seasonal basis only when toxic blooms not present," by Rigby et al. (1993). While the *specific* nature of this option may be less effective (dinoflagellate cysts would be present in resuspended sediments even when blooms are not), we find the philosophy of this approach to be sufficiently distinct from Global Hot Spots (which may be short term phenomena not necessarily related to season) to warrant a separate option category.

Many species reproduce at restricted times of the year, producing planktonic larvae which are in peak densities in certain months (*although these months may vary depending upon environmental conditions*). Thus, for example, zebra mussel larvae may be densest in the water column from May to August (although this too has been found to vary interannually and at different sites in the Great Lakes). Similarly, Asian clam (Potamocorbula amurensis) larvae may be seasonally dense in San Francisco Bay and virtually absent at other times. More generally, spring diatom blooms, comb jelly blooms, scyphozoan jellyfish blooms, and so forth, are normal and typical population phenomena in many inshore waters. These are not, however, "global hot spots" as defined earlier. Note that this option overlaps with the adoption of site- and time-specific macrofiltration management (option 8).

Specific advisories, issued by each state or country, could identify those times of year when the planktonic larvae of certain specific species or groups are densest in the water column, or when natural population "blooms" are in progress. These advisories should *not* be one-time-only, permanent memoranda -- they should be updated as a regularly numbered series. Avoiding the uptake of harbor water at these times would predictably reduce the intake of certain taxa.

7. Site/Time: Do Not Ballast at Night

Avoiding ballasting at night, particularly in shallow waters, will reduce the diversity of species present. ***A prediction is that the sooner this advice can be disseminated to the maritime industry, the sooner we will see a reduction in global invasions of certain species.***

A well-known biological phenomenon is **vertical migration**. Benthic or epibenthic organisms rise up into the water column at night, often to surface waters, and certainly within the depth zones of ships' ballast intakes. This behavior has been related to trophodynamics (feeding), reproduction (mating), and other ultimate or proximate phenomena. Typical species involved are "peracarid crustaceans" -- generally small (in shallow water) crustaceans, sometimes referred to as "shrimp like" (although few are actually "shrimp-like" in any sense at all). Peracarids include amphipods (scuds), isopods (in such families as the Idoteidae, Sphaeromatidae, and Cirolanidae), mysids (opossum or possum shrimp), cumaceans, and tanaids. These organisms can be particularly common at night in the water -- and in many locations *completely absent in the water during the day*. Nektonic species, such as true (caridean) shrimp (such as palaemonids and crangonids) and certain fish and other taxa, may similarly be much more common at night in the upper water

column. We have observed certain species of benthic harpacticoid copepods to be common in night plankton samples in temperate Atlantic coast estuaries and completely absent in day samples (J. T. Carlton, personal observations).

These phenomena suggest that daytime-only ballasting could significantly reduce the uptake of such organisms. Conversely, the presence in large numbers of certain of these taxa (particularly species of peracarids known to be strong vertical migrators) would indicate that the vessel had ballasted at night. Curiously, vertical migration patterns can occur *within a vessel*! We sampled a woodchip bulk carrier with a flooded cargo hold (water depth > 15 meters) both during the day and at night (J. T. Carlton and others, personal observations, Coos Bay, Oregon, 1988). The cargo hold doors were pulled back to expose the hold to natural patterns of daylight. Vertical hauls in the hold taken through the water column at night, combined with visual inspection of the sides of the hold near the water surface, revealed the presence of idoteid isopods and gammarid amphipods not sampled nor seen during the day, suggesting that these species were either on the floor of the hold or on the lower portions of the hold walls during the day. A reverse phenomenon occurred aboard another woodchip bulker during the day: a field team of biologists viewed numerous large (3 mm + length) calanoid copepods in the surface water of the hold *as the doors opened*. These copepods swam down rapidly into the tank (water depth 20 + meters) -- vertical hauls of a plankton net in the top 10 meters of the water column within five minutes collected none of these copepods.

It is of interest to note in this regard the remarks by Walter (1984) that "pseudodiaptomid (copepods)... typically remain near or on the bottom during the day and rise into the water column at dusk, and therefore should be searched for in night plankton samples." Three species of Pseudodiaptomus from China and Japan have been introduced in recent years to the U. S. Pacific coast -- it is tempting to speculate that had vessels avoided night ballasting none of these species would have been introduced.

Prevention of Organism Intake: Mechanical

8. **Filtration**

a. Macrofiltration

Ballast water intakes on most vessels usually have a cover plate (a grate) perforated by many small holes ranging initially from one to two centimeters in diameter (with corrosion these holes may become considerably larger). This plate thus acts as a coarse filter (strainer) for debris and large organisms (fish, crabs, shrimp, seaweeds), but permits many smaller organisms to easily pass through during pumping or gravitation of ballast.

Extended management utilizing the presence of this plate is conceivable. The Lake Carriers Association (LCA) of the Great Lakes has thus proposed (April 1993) a "Voluntary Ballast Water Management Plan for the Control of Ruffe in Lake Superior Ports." This plan is motivated by an attempt to restrict the European ruffe *Gymnocephalus cernuus* to the Duluth-Superior harbor region of Lake Superior. The LCA has suggested that vessel operators "with ballast line intakes equipped with screens with holes larger than one-half inch in diameter" should be restricted at all times of the year in deballasting water from Lake Superior ports into other Great Lakes ports, while operators "with ballast line intakes equipped with screens fitted with holes one-half in diameter or less" should be restricted between May 15 and September 15

relative to pumping out Duluth-Superior water into other Great Lakes ports. These restrictions are based upon the timing of the appearance of juvenile ruffe.

b. Microfiltration

The development of automatic self-cleaning microfilters presents future options for ballast water management with vessel retrofitting or vessel redesign. Microfiltration consists of separating particles between 0.1 micrometers (microns) (1000 angstroms) and 1000 micrometers (1 millimeter). Pollutech (1992) recommended the potential adoption of *wedgewire filters* of 50 micrometer filtering ability. We here examine an alternative filter, the *woven mesh screen filter*, of 25 micrometer filtering ability.

A basic design of a microfiltration system installed in-line on water pipes would be as follows (J. Dragasevich, personal communication, 1992):

"Coarse" microfiltration, consisting of two or more in-line, 30 cm (12-inch) diameter, woven mesh screen filters of 300 micrometers, would be installed as the first filtering units downline from the ballast pumps. Woven mesh, fabric filters are made from synthetic fibers. These units would have protective saltwater coatings. Immediately downline from these units would be two or more (matching) 25 micrometer filters, which are now available. Both sets of filters are self-cleaning units, using approximately 130 gallons of water per wash. The coarser 300 um filter uses a brush filter mechanism (operating at 150 psi minimum), which can be continuous during system operation (brush filters are used in heavy particle load industrial systems, such as "white water" in pulp/paper processing mills). Stainless steel brushes, driven by a 1.5 HP motor, revolve along the screen, removing the filtrate which is then discharged through a flushing valve for a duration of 15 to 20 seconds. ***This first filter would remove most of the larger zooplankton.***

The finer 25 um filter uses a suction scanner filter mechanism (operating at 30psi minimum), where cleaning also occurs while flow continues (flow reduction during the cleaning cycle is minor compared to system flow). The suction scanner, also driven by a 1.5 HP motor, scans the filter screen in a spiral motion and removes the filtrate with suction caused by the flushing valve opening to the outside. The hollow wings of the scanner collect the filtrate and pass it to the flushing valve without touching the screen; cleaning takes 40 to 50 seconds. ***This second filter would remove most of the smaller zooplankton and most of the large and medium-sized phytoplankton.***

These filters can be computer programmed, relative to automatic cleaning at specific time intervals or at specific pressure differences across the filter.

Residues (filtrates) collected by these filters are either collected and disposed of later or flushed out of the system at the time of ballasting. If the latter, these residues would be flushed out within the hydrographic region where the water was being boarded, rather than at the destination port (which would have the potential effect of releasing living organisms in the filtrate at the new port).

Capacities of these filters at 300 um and 25 um would be up to 1000 cubic meters/hour (264,000 gallons per hour). Double systems would thus be capable of boarding over 525,000 gallons per hour. As noted earlier, most vessels operate with pump capacities of less than 1,000 cubic meters/hour and thus these filters would not slow most modern ballasting operations. It is

probable that installation of microfiltration equipment would require up-sizing existing vessel pump capacities, or using more pumps, to overcome the additional resistance developed (discharge head pressure) by the filtration equipment. The alternative (not upsizing the pumps or using additional available pumps) would be that there would be a reduction in the capacity of the pumps dependent upon the actual additional head pressure encountered and the operating characteristics of the pump.

Woven mesh filters have a number of advantages over wedgewire filters. Wedgewire filters, while rated at 50 um or better, due to their slotted design, permit larger non-spherical particles to pass through lengthwise, effective below 100 um (J. Dragasevich, pers. comm., 1992). These filters thus permit a large number of invertebrate larvae (including the larvae of zebra mussels) to pass through. In wedgewire filters a relatively small proportion of the filter surface (estimated as about 5 percent with a 50um filter) is actually available for filtration, since the wire takes up much of the surface area of the filter; in a woven mesh filter, considerably more of the surface is open and available for filtration (estimated as about 37 percent with a 50um filter). Wedgewire filters self-clean by backflushing, such that there is flow reversal and thus at least one pump of the system is off-line during the backwash process. Previously filtered water is used for backflushing, with this water thus lost to the discharge; in woven mesh systems, unfiltered water is used to clean the system. In the cleaning process, a woven mesh filter is generally 100 percent effective, removing all filtrate larger than the specified size; a wedgewire filter may be partially self-cleansing only, backflushing going to the area of least resistance. Backflush water must be at least 10psi greater than inlet pressure, and therefore the operation requires an additional booster pump. In addition, considerably more water (as much as 2500 gallons per wash) is required, while a woven mesh filter, using brush or suction cleaning, requires no extra pump and only 132 gallons/wash (at 60 psi).

A second in-line, follow-on control system, downline from the microfilters, could be placed to achieve removal of organisms < 25um in size. Options include UV (option 11), ultrasonics (option 12), or a chlorine/iodine solution injected by metering pump (followed by chlorine and iodine removal) (P. Messier, personal communication, 1992). Chemical injection at the pump followed by removal is discussed at Chemical Biocides (option 14).

Woven mesh filter systems are large and would require vessel retrofitting or be applicable to new vessel design. A wovenmesh filter system as described above measures 2.8 meters in height by 1.7 meters in width; side-by-side double filters would thus require at least 3.5 meters. Two brush model 300 micron, 1000m^3/hr capacity filters cost approximately $32,000; two scanner model 25 micron, 1000m^3/hr capacity filters cost approximately $40,000. Maintenance of these systems is said to be low, with screen replacement being required every few years.

A limitation to implementation of filter systems would be among those vessels using gravitation for ballasting. Requirements to pump all water aboard (and through filters) rather than gravitate water aboard would need to be examined.

Extermination of Organisms Upon Ballasting (Ballast Treatment)

9. Mechanical Agitation

a. Water Velocity

Increasing the rate of water flow has been proposed as a means by which organisms would be mechanically destroyed. While there is little question that many organisms would suffer increased mortality under very high velocities (presumably by being crushed against solid objects with which they would collide, or by being trapped in cavitations), there are little or no data on the potential efficacy of this method. Ships' ballast pumps are for the most part high volume, low pressure systems, and are not designed to achieve very high velocities (Helland, 1991). Many organisms safely transit the existing centrifugal ballast pumps, which typically operate at 1200-1800 RPM. Ballast water sampled via deck outlets through fire control systems, normally a higher pressure and higher velocity environment than the ballast systems, have been found to usually contain living organisms.

b. Water Agitation Mechanisms

A corollary of option 9(a) is the installation of specialized water agitation mechanisms which would create high velocity jets and gyres of water in the pipes or tanks. The retrofit and high maintenance costs of such devices combined with the poorly known effectiveness of such treatment argues against this option.

Mechanical agitation of the water for sterilization is not a probable pursuable pathway.

10. Altering Water Salinity

a. Add fresh water to salt water

b. Add salt water to fresh water

Treatment 10(a) presumes that sufficient dilution of saltwater ballast by the addition of freshwater would lead to the mortality of the saltwater organisms (via disruption of physiological, osmoregulatory processes). The amounts of freshwater necessary would naturally vary with the ballast load. For full salinity seawater (for example, 30 o/oo [parts per thousand] and above), reduction by over half (to 15 o/oo) would probably be necessary to kill many organisms, but the mortality levels in differing salinities for most marine and brackish water organisms differ very widely, and no real generalizations can be made. The eggs, larvae, spores, seeds, juveniles, and adults, of saltwater species may further vary in their salinity tolerances. In order to achieve a reasonable level of mortality, a very large amount of freshwater would likely have to be added to the saltwater ballast -- to the point that if such amounts of water were available a more reasonable approach would be to simply take on freshwater as ballast.

An emergency or back-up option for vessels unable to exchange their seawater ballast is suggested by this approach. Where larger rivers exist near coastal ports, a vessel could proceed up river and if the ship was only in partial ballast, add to capacity freshwater ballast in an attempt to kill the saltwater organisms. Post-ballasting sampling would be necessary to determine the effectiveness of this strategy.

Treatment 10(b) refers to the active addition of salt or saltwater into already ballasted tanks. Having available sufficient supplies of sodium chloride, or saltwater itself, at the port of origin would be problematic. This treatment in turn presumes that sufficient addition of saltwater to freshwater ballast would lead to the mortality of the freshwater organisms (via disruption of physiological, osmoregulatory processes). The amounts of saltwater necessary would similarly vary with the ballast load. The salinity tolerances of freshwater (0 - 0.5 o/oo (parts per thousand)) organisms vary widely, and few generalizations can be made. As discussed at option (22) below, and detailed in Table 6-6, broad tolerances to submergence in saltwater may be particularly true of the highly resistant encapsulated or encysted stages of many species.

In freshwater-saltwater-freshwater transits (such as vessels from foreign freshwater ports bound for the Great Lakes or other freshwater ports), it is more likely that the vessel would await passage through saltwater (options 20, 22). In freshwater-freshwater transits (such as within the Great Lakes), the addition of salt or saltwater to the ballast may provide a means by which to control the intra- and inter-lake ship-mediated dispersal of nonindigenous species, such as the ruffe, by a chemical that may be absorbable within a large enough body of freshwater (such as the Great Lakes) simply as a result of volumetric dilution.

11. **Optical: Ultraviolet Treatment**

Although the lethal effects of ultraviolet light (UV-B and UV-C) on marine and freshwater planktonic organisms remain unstudied for most species, UV sterilization of ballast water, as a non-chemical option, remains a possibility, especially in conjunction with other control options such as microfiltration. UV acts upon the genetic material (DNA) of exposed organisms and upon chloroplasts of phytoplankton. UV exposure has proven 100 percent effective in preventing the settlement of barnacle and other larvae on transparent pipes (Plotner, 1968). UV would be effective in both fresh and salt water systems, and has the potential to kill organisms from viral-bacterial size levels to invertebrate and chordate larvae.

An operative UV system could consist of either,

(A) in-line flow treatment
(B) within-vessel recirculation
(C) portable units for on-board sterilization (deployable tank-by-tank)

In addition,

(D) UV systems at the ballast seachest intake may cause certain organisms (such as fish) to avoid the region and thus not be drawn into the ballast system
(E) UV treatment facilities could be installed on lightering vessels or barges (option 28).

Precursors for the use of UV to treat ballast water as it was loaded (or discharged) at volume flows (thousands of cubic meters/hour) greater than necessary for most ballast systems (hundreds of cubic meters/hour) are found in municipal water plants, which use mercury vapor lamps in the 254nm range and at power levels of 30 to 35 watts (these are usually post-chlorination treatments). As power input increases, necessary exposure time decreases, although this is not a direct linear relationship. Transmittance depends on clarity of the water, and while UV should be effective at low transparency levels, waters laden with sediment may reduce UV effectiveness.

Nevertheless, UV could also have some limited depth penetration (to two or more centimeters) in ballast sediments.

Relative to (A), in-line flow treatment, UV lamps (such as xenon arc lamps) could be installed on (rebuilt transparent) ballast pipes, irradiating and exposing the organisms in flowing water to high intensity UV light. Although experimental data are lacking, short exposure times (for example, 20 seconds) at higher power levels (1000W) over a distance of < 20 meters would theoretically be biocidal to a large fraction of the life in the water. Effective UV ranges for biocidal activity in ballast water are likely to be in the range of 254 to 320 nm; within this range UV has proven highly effective in preventing larval settlement. Wave lengths of < 200nm are absorbed by dissolved "yellow" (organic?) materials in the water column. In-line flow treatment could be applied at both ballasting and deballasting. UV activation could be tied automatically to flow levels and kept at low levels between ballasting operations to prevent coating of the transparent tube.

Relative to (B), within vessel recirculation could be effective with water passing or being held in UV exposure units.

Relative to (C), portable hand-held, high power UV lights provide a potential technology for the sterilization of smaller tanks under static conditions after vessel arrival (the operator would use protective gear; UV is absorbed by almost all materials). UV light in the 280-320nm range would have a penetration of about 4 meters in the water column; greater penetration would be achieved at higher frequencies, but the depth is not necessarily proportional. Presumably such units would be primarily useful if lowered into upper wing tanks from deck level; other tanks which would require actual entry or diver placement would modify the usefulness of this approach.

Safety issues appear to be minimal with the use of appropriate protective devices around the UV sources and with the use of protective clothing. Safety and personnel training would be required. Ozone is a byproduct of UV, but nitrogen addition and proper pipe bleeding would avoid human health concerns.

UV is a retrofit option, requiring (in scenario (A)) the ballast systems to go off-line while new piping is installed and lamps fitted. UV lamps > 1500 W with power source would cost more than $10,000; new generation lamps have an approximately 10,000 hour life. Vessel retrofit costs would be dependent upon many of the criteria noted in Box 6-2.

UV is a potentially highly effective alternative, with high environmental and human health acceptability, but field trials will be required relative to effectiveness at various flow rates and sediment levels. Small UV systems are already aboard some vessels, such as on ACV container ships, where they are used for potable water, but flow rates are very small (H. Nilsen, Sea Land, personal communication, 1992).

12. **Acoustics (Sonics): Ultrasonics Treatment**

High intensity ultrasound induces three types of responses effective in biocidal activity (Fischer et al., 1984): cavitation, heat generation, and pressure wave deflections. The use of ultrasonics to control hull fouling on ships dates back to the early 1950s; within 20 years, experiments had been conducted on the effects of pulsed ultrasonics (between 28 kHz and 200

kHz) on barnacle and mussel larvae, in confined laboratory cultures, with the higher frequencies being more effective in larval mortality (Suzuki and Konno, 1970). Cavitation is produced in the water column and is affected by the frequency of ultrasonics applied, the power level, the volume of water, the presence of dissolved gases, total dissolved solids, and the temperature of the medium (cold requires higher power levels).

However, the potential application of ultrasonics in eliminating plankton from large volumes of water, either static or moving, remains largely uninvestigated. Ultrasonics can kill organisms as small as bacteria in a flowing stream of water (M. Kenna, personal communication, 1992); the statement in Pollutech's report (1992) that ultrasonics is "not effective against organisms smaller than approximately 150 um" appears to be in error. Plankton death may be caused in part by the cavitation process, ranging from simple "system shock" to extensive physical disruption of the living tissue of the animal. The *effectiveness* of ultrasonics sterilization depends upon exposure time, which in turn is related to flow rate, pipe diameter and effective pipe length (thus in a ballast system a method for increased exposure time without affecting pumping rate would be to establish parallel piping systems, each pipe with ultrasonic transducers). Up to 66 percent mortality to zebra mussel larvae has been achieved when the veligers were exposed to 40 kHz for 3.0 seconds in a 10" diameter , 36" long pipe, at 224 gal/min (M. Kenna, personal communication, 1992). Up to 94 percent mortality was achieved with 6 second exposure in a 3" diameter pipe at 50 gal/min (M. Kenna). Saltwater would likely require a longer exposure time to cause mortalities than freshwater due to dissolved particulates.

As with UV application, implementation of ultrasonics would require the on-line placement of transducers in replaced sections of ballast piping. On-line application in a flowing water system of sufficient pipe length would be the probable first line of experimental work. *In situ* application of ultrasonics within ballast tanks and holds might result in "shadow effects" (if not tailored to the particular application) and ultrasonics would probably not penetrate several cm of ballast sediment.

Although there are many variables, ultrasonics would likely require more energy than UV systems. Certain transducer types can make an "annoying" noise, which however can be muted; no medical problems have been identified with ultrasonics exposure (M. Kenna, personal communication, 1992). Ultrasonics will degas the water and thus reduce oxygen levels (which may also, in turn, enhance animal and plant mortalities). If large amounts of oxygen are removed, metal corrosion problems may ensue due to the build up of anaerobic conditions. Furthermore, there is a remote possibility that tank corrosion may occur or increase as a result of cavitation due to physical damage to tank coatings or tank structure.

As with microfiltration and UV, experimental work, scaled to ship ballasting parameters, are now required to test the effectiveness of this technique.

II. ON DEPARTURE AND/OR WHILE UNDERWAY (EN ROUTE)

Active Disinfection (Ballast Treatment)

13. Tank Wall Coatings

Toxic antifouling paints, or other biocidal coatings, could be placed on ballast tank walls. This would not be an option for ballast water held in cargo holds. Surface coatings usually act as

contact poisons and would not (except, theoretically, for extensive leaching into small, closed, non-circulating systems) be biocidal to planktonic organisms dispersed in the ballast water, nor to organisms in ballast sediments. Antifouling paints would prevent the development of fouling organisms in ballast tanks, but this is not a high profile concern (attached fouling organisms on the walls of ballast tanks have not been recorded). The use of antifouling paints in seachests may have more value.

14. Chemical Biocides: Addition of Chemicals to Water and Sediments

A lengthy list of chemicals that kill aquatic organisms now exists. Such chemicals could be added to ballast water and sediments or derived in part from diesel engine emissions (whose main components are nitrogen oxide, sulphur oxide, carbon monoxide, and hydrocarbons; Hellen, 1990).

Particularly effective are oxidants, the "oxidizing biocides," including chlorine (in various forms, such as sodium or calcium hypochlorite and chlorine dioxide), ozone, potassium permanganate, hydrogen peroxide, bromine, and choramine. Of these, water chlorination has become most common. In standard power plant systems chlorination consists of converting liquid chlorine (for large plants, stored in 55 ton rail cars) to gaseous chlorine, which in turn is injected into the cooling intake pumps. In the past 20 years aggressive environmental legislation has sought to control the amount of chlorine discharged into ambient waters. High levels of chlorine create not only environmental concerns, but may cause corrosion and form toxic by-products (such as trihalomethane compounds). Amelioration of the disposal of chlorinated water by dechlorination can be achieved through the addition of reducing agents (such as sodium thiosulphate or sodium metabisulphite), but the amounts needed and methods of application of these in ballast systems aboard vessels are (as discussed below) perhaps no less complicated than the application of chlorine itself.

The efficacy of most of oxidizing biocides against most individual species of aquatic (freshwater, marine, or brackish water) organisms (bacteria, viruses, invertebrates, fish, algae, and others) is not known, but is assumed based upon general biocidal profiles.

With exceptions as discussed for individual control options, chemical treatment is not as likely an avenue for management and regulation of ballast water, although its use under emergency conditions is not precluded (see "Note on Chemical Application in Emergency Situations," below). While some vessels may use chlorination on a relatively small scale for control of fouling organisms in seawater systems or in on-board sewage treatment plants, the volumes are very small compared to the amounts that would be required in ballast management. For the following 17 reasons chemical options are not currently recommended as major future avenues for immediate research:

(1) ***Human Health and Safety -- Chemical Handling:*** The shipping industry has, with very rare exception, no experience with the on-board use and internal application within the ship of *large* amounts of poisonous chemicals. The potential risks to personnel safety due to accidents that will occur are considered to be high.

(2) ***Human Health and Safety -- Indirect Exposure:*** Many chemicals may evaporate, evolve gases or produce other by-products that would require special venting from ballast tanks or holds into regions where humans are not likely to breath the air.

Most ballast tank openings and outlets vent at deck level, and are not aerodynamically engineered to move air high into the atmosphere. The use of scrubbed flue gases as biocides routed through ballast tanks and ballasted holds would in particular appear to pose numerous potential health hazards through leakage, venting, and accidental exposure to toxic fumes.

(3) *Environmental Concerns -- General:* There is a rapidly growing trend and desire globally to reduce the amounts of poisonous chemicals added to the environment. Requiring chemical treatment of hundreds of billions of gallons of ballast water per year globally would likely be received with great local, national, and international resistance in most environmental, political, social, and economic arenas.

(4) *Environmental Disposal -- Regulatory Procedures:* Chemical disposal regulations in nations around the world vary to the point that the mariner, with chemically-treated water aboard, would need to interface with a vast new set of regulatory procedures on a country-by-country basis, if not at even more local levels.

(5) *Environmental Disposal -- Monitoring:* Vessels would be required to have aboard and properly use post-application chemical monitoring equipment, to determine the levels of chemicals remaining in the water prior to overboard water discharge. The large amounts of water carried by many ships would require that one or more crew members be trained as chemical technicians and devote some portion of their watch time to chemical monitoring.

(6) *Environmental Impact -- Non-Target Systems:* Environmental disposal of chemically treated water may unintentionally poison non-target species in ambient waters. Deactivation of applied chemicals may alleviate this concern, although accidental discharge (spills) of chemically-treated ballast water may occur prior to chemical deactivation, or no deactivation may be possible.

(7) *Ballast Applications - General Standards:* The great diversity of vessel types and, concomitantly, ballast pumping, ballast tank and ballasted cargo hold variations, argues against a standard set of chemical application procedures. Injection of chemicals into the ballast stream on intake is a potentially complex, costly, and hazardous procedure.

(8) *Ballast Applications -- Chemical Access:* The direct (through-hatch or at the pump) or indirect (through hard-piping leading to the ballast tank) access to ballast-holding systems varies virtually to the level of the individual ship. On many vessels direct access is very difficult to impossible (an example of the latter would be filled tanks with vertical access hatches or access blocked by cargo), and chemicals would need to be added through sounding tubes or other pipes. The resulting actual application dosages and actual in-tank mixing would vary to the point that the reliability of treatment would be unclear at best. Vessel refit for the installation of a network of chemical injectors is possible with concomitant economic investment (refit is not unique to chemical options).

(9) *Overall Effectiveness -- Ballast Sediments:* The effect of the target chemical on

reaching ballast sediments, mixing with the sediments, and maintaining biocidal dosages after passage through large amounts of water would be limited to non-existent.

(10) *Overall Effectiveness -- General Biocidal Nature:* The actual effectiveness of any one chemical as a complete biocide against all organisms existing in a given tank or hold of water is, with exceptions, likely to be limited. Similarly, the dosages required of most chemicals to effect nearly 100 percent sterilization are not known. This caveat, however, is not unique to chemical treatment.

(11) *Compatibility with Ballasted Cargo Holds:* Chemicals of any nature are unlikely to be applied to dual- or multiple-use tanks and holds. On some trade routes very large amounts of ballast water aboard a vessel are held in cargo holds. Extensive cleaning and testing for quality assurance would be required after chemically-treated ballast water was discharged and before cargo was loaded in the same tanks.

(12) *Potentially High Costs:* Many ships on most trade routes, and most ships on some trade routes, carry vast volumes of water, in the tens of millions of gallons per trip. This would require bringing or having aboard on every leg where ballast water is used chemicals (and comparable post-application deactivation chemicals if such exist) that could cost tens of thousands of dollars per voyage.

(13) *On-Board Handling and Procedures:* Extensive on-board storage, routing, security, safety measures, packaging disposal, spill clean-up, inventories, and (for some chemicals) air and water monitoring would be required, at very high expense.

(14) *Handling Time:* Compared to sterilization strategies with more automatic components (such as UV or filtration), handling time is large if manual application is required, which would be the case for most if not all vessels.

(15) *On-board Chemical Stores would be Large:* On-board chemical stores would have to be very large, as the reliability upon the availability of any one chemical, and in the quantities required, at any given port would be unclear. The volumes may interfere with cargo-carrying capacity.

(16) *Vessel Refit for Storage Systems:* Vessel refit would be required for the proper installation and ventilation of storage areas ranging from leak-proof rooms to leak-proof tanks of the highest grades. Vessel refit, however, is not unique to this control option.

(17) *System Chemical Ad-/Absorption and Corrosion:* Most ship's systems, of metal, plastic, glass, or other materials, are not pre-designed to sustain exposure or resist adsorption or absorption of most biocidal chemicals. In some instances corrosion on tank and hold walls may increase.

Note on Chemical Application in Emergency Situations

Chemical application remains an emergency procedure in the repertoire of state

authorities faced with a vessel that has arrived in port and that has been determined to have aboard ballast water and/or sediments of high environmental and/or human risk. Examples would be ballast determined to carry human health pathogens (such as cholera bacteria) or other organisms of a high noxious profile (such as toxic dinoflagellates). In these cases, however, it would appear more likely that the vessel would be immediately placed in a "Discharge Prohibited" status (see "Integrated Ballast Management", below), and be asked to depart and dispose of its water outside the state's jurisdictions. Failing this, the application of biocidal chemicals and their subsequent natural decay over time or deactivation by the addition of other chemicals could be considered.

15. Ozonation

Ozone is an unstable oxidizing biocidal chemical. In addition to the considerations discussed under "Chemical Biocides" (for ozone, especially its quality of being a highly toxic irritant), which considerations would argue against the use of such chemicals, ozone could act as an important corrosive agent in ballast systems. The application of ozonation to ballast systems is potentially complex, and may require further special study.

16. Thermal Treatment

The success of thermal treatment in the general control of fouling organisms in seawater pipe systems, particularly the well-known effects of relatively small increases in temperature causing significant mortalities in such organisms as mussels and barnacles (Fischer et al., 1984) has led to the suggestion that heating ballast water would be a potentially effective biocidal technique. In retrospect, thermal treatment is a marginally pursuable option, perhaps applicable to new vessel design.

Two possibilities exist by which ballast water could be heated: (1) heat, either generated specifically to warm the water, or already produced by the ship, could be re-routed to warm the ballast, or (2) the ballast water could be re-routed to the ship's heat source.

In the first case, ballast tanks could be retrofitted with heating pipes. Some smaller sized oil tankers and general cargo vessels are fitted with steam heating pipes running through some of their ballast tanks, and could conceivably heat some of their segregated tanks in this manner (Schormann et al. 1990). The costs of retrofitting, which would be very high, are dependent upon a large number of vessel-specific criteria (see Box 6-2). Main engine heat-producing capabilities vary with vessel type and engine size and age, and it is impossible to predict whether vessels in general would be capable of producing the required heat. For many vessels, it appears that they would not be able to do so. A further dependent variable is the length of the voyage between ports.

In the second case, ballast water could be re-routed to the engine room, and with retrofitting conceivably be part of the engine cooling water cycle. The costs of new piping to move all ballast water through the engine system could be extremely high. For most vessels, more water than that typically held by a ship would be used during the engine cooling cycle of one voyage, and thus at some point already heated ballast water (assuming the water was sufficiently heated in a single pass) may circulate back and be less effective as a cooling agent (although the vessel could then switch to ambient water). However, a once-through passage by ballast water through the engine cooling system may be relatively ineffective at raising the water to a sufficient

temperature and keeping it at an elevated temperature.

Additional anticipated difficulties with thermal treatment are as follows:

(1) The thermodynamics of heat transfer in large volumes of water aboard vessels not designed to carry heated liquids is poorly understood. Heat causes expansion, and the rate of heat conduction to non-target areas (hull, bulkhead, internal spaces, cargo spaces) of the vessel must be considered in terms of thermal stress to the vessel.

(2) Conversely, heat loss from the ship would be difficult to prevent, and cooling (relative to tank volume) may be rapid. On most vessels ballast tank walls are typically the hull of the vessel.

(3) Many tanks, particularly peak and wing tanks, are deep and wedge- or irregularly-shaped, such that even heating of the water, even if fitted with heating pipes, would be difficult.

(4) Ballast water held in cargo holds is not likely to be subjected to heat treatment by the methods discussed here.

(5) The discharge of the heated water, as a thermal plume, to the ambient environment, may be subject to local environmental regulations.

(6) As with ultraviolet light and ultrasonics, the heat levels necessary to achieve mortality of many species are not known, and may vary considerably relative to life-history stage of the organisms involved. The resting stages of many aquatic organisms (Table 6-6), as with other systems, may be resistant to thermal treatment. Suchanek and Grossman (1971) found that many larval polychaetes survived well in temperature elevations that raised discharge temperatures at a power plant in Long Island to near 38° C (where ambient summer temperatures may be 25° C), with 63 percent of the individual planktonic worms collected in the discharge water being alive.

It is improbable that an existing vessel would be redesigned to account for all of these obstacles. Newly designed vessels, however, could conceivably incorporate the required technology by designing ballast tanks in a manner similar to tanks now carrying high-temperature cargoes. An example of a potential model vessel is the *Theodora* built in 1991 (Merwede Shipyard, The Netherlands; DWT 6600; cargo capacity 5245 m^3, ballast capacity 2195 m^3) (Significant Ships of 1991). The *Theodora* is designed to carry boiler oil, coaltar naptha, creosote, antracene oil, and other liquids at temperatures varying from 40° C to 250° C, in three steel tanks resting on flexible foundations welded to the ship's bottom structure, thus allowing expansion and contraction in both vertical and horizontal directions, depending upon cargo temperatures. Heating coils are fitted in each tank, supported by two 817,000 kcal/h twin-burner boilers. This capacity permits a 10° C cargo temperature increase in 24 hours. Rockwool with aluminum foil provide insulation, allowing only a 3° C drop in temperature over 24 hours (of cargo at 250° C) and at an outside temperature of 10° C.

Flexible foundation ballast tanks, high production heating coils, and proper insulation

would be integral to new vessel design (as opposed to retrofitting). Inboard cooling systems may be required to address the problem of heated effluent discharge. Removable insulation could allow ballast to return to ambient temperatures before arrival at the next port for discharge.

Thermal treatment is not a likely option for application to present day vessels, even for retrofitting. The *Marine Pollution Bulletin* in fall 1992 (24(11):528-529) citing a report in *Lloyd's List* notes that "Australian scientists are attempting to develop a ship engineering design in which heat generated by the engines is used to kill off alien organisms taken in with ballast water..... For a 45,000 ton ship, heat generation power of 45 megawatts would be needed to do this, on top of the 20 MW of waste heat from the ship's main engines".

17. Electrical Treatment (including Microwaves)

Electrical treatment has been applied for a number of years to the control of fouling organisms (Fischer et al., 1984). Seawater, however, because of its high ionic composition and accompanying conductivity, limits the usefulness of the application of electrical currents and fields. Higher power inputs are more effective (for the control of fouling) but are costly (Fischer et al., 1984). Large scale application of electrical fields to saltwater ballast would also have major implications for human safety and health concerns.

Microwaves as a control technique are not an option (L. Otten and L. Braithwaite, personal communications, 1992). Microwaves would operate to heat the water, but effective levels would be low (microwaves are 50 percent attenuated in only 11 cm of distilled water). More importantly, the size and costs of a microwave unit to heat ballast tanks would be prohibitive: a 50KW microwave generator costs about $2 million, and such a unit would be too small to microwave one large ballast tank. In addition, heat loss would be enormous from the tanks and ship.

Microwaves are not a pursuable control option for ballast water.

18. Oxygen Deprivation

The adding of chemicals (such as sodium metabisulphite with cobalt chloride as a catalyst) to water to create anaerobic conditions has been widely proposed as a control option for a number of aquatic nuisance organisms. Because of (a) the difficulties of sealing ballast tanks and associated air pipes (and the need for pressure relief valve retrofitting) for full effect of chemical oxygen scavengers, (b) the potential for large generation of hydrogen sulfide (with concomitant corrosion effects), the on board accumulation of sulfur compounds, and (c) the potential discharge of anoxic, sulfur-rich water, oxygen deprivation is an unlikely option to be pursued. Oxygen deprivation may also have minimal effect on encysted stages of many organisms.

19. Filtration/Ultrasonics/Ultraviolet Underway

Ballast water could be *recirculated* through self-cleaning filters, or ultrasonics or ultraviolet systems, while the vessel was underway, rather than (or in addition to) such treatments while the water is being boarded. These specific alternatives have been discussed earlier. A vessel fully equipped to undertake such treatment, however, would likely apply these procedures upon ballasting, rather than devoting crew time to water processing at sea. Recirculation systems within the vessel would have the potential of requiring more space than initial intake, on-line treatment

systems. However, should experimental work on filtration, ultraviolet, or ultrasonics demonstrate an unacceptable time delay in ballasting, whereas *in situ* treatments while the vessel is underway, while requiring more time, would be effective, en route treatment may prove to be a pursuable option.

20. **Altering Water Salinity: Partial Exchange**

We newly distinguish this as a ballast control option. The specific intent of this procedure is to flood and mix fresh water ballast with salt water, or salt water ballast with fresh water, in order to use the newly ballasted water as a biocidal agent. The principle behind this technique is to directly impact those species whose osmoregulatory abilities are unable to compensate for marked changes in water salt concentration. This procedure would normally require partial deballasting followed by reballasting (partial exchange).

Captains of certain vessels have informed us that they could not fully exchange their water in certain tanks (such as upper wing tanks) because of potential stability problems. Option 20 identifies the potential usefulness of even partial exchange of such tanks if a vessel finds itself in water of distinctly different salinity than that of the ballast water aboard. Locke et al. (1992a, b) found numerous dead freshwater organisms in partially exchanged salt water in European vessels arriving in the Great Lakes. The presence of these dead organisms in the tanks is evidence that even though exchange was partial, the increased salinity was of sufficient magnitude to kill most freshwater organisms.

Passive Disinfection

21. **Increase Length of Voyage**

Williams et al. (1988) found that the number of taxa in ballast water decreased as the length of the voyage increased. Water approaching one month old had relatively fewer living organisms.

There is no doubt that mortalities occur in ballast tanks and ballasted holds over time (see Box 6-4 for a discussion of this phenomenon). However, the diversity of conditions (water quality, rate, direction and level of temperature changes, and oxygen content,as mixing of older with "newer" (reballasted) water), suggests that an extraordinarily wide set of conditions could result in an equally broad set of *in situ* situations that would lead to the continued abundance of some species over a relatively long period of time. Moreover, the resting stages of many organisms (see Table 6-6), in particular dinoflagellate cysts, would likely remain viable in tank water or sediments for lengths of time far exceeding those under which it would be practicable to increase a voyage transit or hold the water.

The economic climate of the maritime industry, which seeks to minimize rather than lengthen the transit time of a vessel, argues against continuing to consider this an optional control measure.

BOX 6 - 4

WHY DO NATURAL MORTALITIES OCCUR IN BALLAST TANKS AND BALLASTED HOLDS?

Natural mortalities of animals and plants do occur in ballast water during the voyage. There have been few studies, however, comparing the originally ballasted assemblage to the arrival assemblage in a given vessel. Figure 4-6 illustrates a theoretical sequence of events in the movement of organisms in ballast water. With each subsequent stage the "box" becomes shorter, reflecting increased mortality (and thus decreased number of species). The width of the filter remains the same, however, reflecting in part our lack of knowledge of the mechanisms involved in reducing the abundance and diversity of organisms between each step. Earlier studies conducted at Woods Hole (see Carlton, 1985), comparing stages I, II, and III, revealed that stage II was generally comparable to I (although some species present at shipside were not ballasted up). Stage III assemblage often showed a decrease in the number of species after a voyage, but did not necessarily show a decrease in the numbers of individuals of those species that did survive.

Why would animals and plants naturally die in a ballast tank? *In situ* phenomena leading to mortalities potentially consist of:

Biological Alterations:

(a) *Predation* by other organisms, such as fish, hydromedusae, and larger crustaceans.

(b) *Decreased food supply*, or, for visual predators, the inability to locate food, potentially leading to starvation.

Physiological Limitations

(c) *Mortality of meroplankton larvae*, due to their inability to delay metamorphosis in order to locate a suitable settling site (starvation is noted in (b), above).

(d) *Absence of light* for photosynthesizing organisms, such as diatoms (phytoplankton).

Physical-Chemical Conditions

(e) *Temperature changes*, due to the "natural" heating or cooling of the water as it passes through different water masses.

(f) *Oxygen changes*, such as decreasing dissolved oxygen levels.

(g) *Water contamination*, due to shipboard sources of contaminants (such as greases and oils) or to pollutants taken on board with the ballast water.

Relative to (e), the duration of exposure to altered temperatures followed by the return to original temperatures may play an important role; the length of time it takes a vessel to pass through tropical waters would be an applied example. Studies in 1980-1981 at Woods Hole (Carlton, 1985) revealed a wide range in the efficacy of natural water heating (that is, a vessel sailing into warmer waters), such ranges depending upon whether the ship continued unidirectionally into warmer waters, or returned to cooler waters. In plankton ballasted on Cape Cod in winter, there was surprisingly high survival of crustacean zooplankton (such as copepods and barnacle larvae) in ballast water that had departed Woods Hole at about 4 degrees Celsius, heated up to 25 degrees Celsius (for a period of only several days), and then cooled back down to ambient Cape Cod temperatures upon return.

22. Exchange (Deballast and Reballast)

Ballast water exchange is also called *at sea, open ocean, deep water, high seas*, and *mid-ocean* exchange (see Box 6-5 for a discussion of these terms). Exchange is the process of **deballasting** followed by **reballasting**. Deballasting alone is not considered to be exchange (although, if done at the "proper" sites (see below), it may achieve the same management objective). Under current Canadian, U.S., and IMO guidelines or laws, exchange is advised in waters with depths greater than 2000 meters.

Exchange is accomplished in one or more of three possible ways:

(a) **deballast and reballast:** by pumping or gravitating out of the vessel's tanks (normally one tank or paired tanks at a time to maintain stability (GM)) and holds as much of the water as is possible (with minimal or no compromising of the stability or other needs of the vessel), followed by pumping back into the tank compensatory water.

(b) **flushing (flow through, overflow)**: by pumping water into the vessel's tank or holds such that the water at the top of the tank/hold system overflows, usually through an overflow vent, or a deck pipe. Flushing would have to be extensive to approach full exchange. Hutchings (1992) has noted that Australian studies in progress indicate that more than three flushes were required "to ensure the complete replacement of water."

(c) **tank topping at sea:** Jones (1991) describes this as a process "involv(ing) the partial pumping out of a tank, followed by filling as the pumping out continues, then final refilling." This would require two separate ballast pump-piping systems for such a simultaneous operation. If deballasting was by pumping and simultaneous filling (reballasting) was by gravitation (or vice-versa), two separate openings to the surface and into the tank (hold) would be required. We did not encounter this procedure in our work.

Why vessels "normally" deballast and reballast as part of ship's operations is summarized in Box 4-2.

There are two major biological and ecological principles that provide the scientific foundation for exchange:

(1) If exchange occurs far enough from the continental margin, **the probabilities of reciprocal introductions are virtually non-existent.** The oligotrophic (low food) conditions, higher ultraviolet radiation levels, high salinities, predators, and other conditions of the oceanic environment create inhospitable (if not immediately biocidal) conditions for freshwater, estuarine, or most inshore coastal (neritic) planktonic organisms discharged into this environment. Conversely, oceanic organisms ballasted up in their place, and later discharged into freshwater, estuarine, or inshore coastal (neritic) waters will encounter similarly hostile conditions.

BOX 6-5

WHICH IS IT?: AT SEA, MID OCEAN, DEEP OCEAN, OPEN OCEAN, HIGH SEAS EXCHANGE

The terms, "at sea," "mid ocean," "deep ocean," "open ocean,", and "high seas" have all been used in reference to the possible location of undertaking exchange of coastal ballast water. As the eventual adoption of one or more terms has the potential to influence the perception of a "proper" and "effective" site of exchange, a careful consideration of the appropriate term may be beneficial in the early stages of international ballast control. Because of the global diversity of the relationships between coastlines and the proximity to "open" or "deep" ocean, location-specific definitions of exchange sites, rather than a simple phrase, may prove to be more useful in the long run. Legal definitions (international and national) of ocean regions are available; a detailed review of these, as potentially applicable to exchange sites, could be a useful exercise.

At sea is a very general mariner's term referring to the vessel being *at some distance away from the port or harbor.* As such, it does not connote any specific distance from land nor depth of water. It is sufficiently imprecise as to suggest avoidance of this term in the context of ballast exchange.

Mid ocean indicates the mid-point of a voyage between two land masses. Under current IMO/MEPC guidelines, water depths of 2000 or more meters are suggested as appropriate sites for exchange. In all major ocean basins these depths occur relatively near the continental margins (shelves), and are not restricted to mid oceans. Mid ocean exchange in major ocean basins (as discussed elsewhere) may approach "ideal" exchange (in the sense of the unlikelihood of any released plankton ever reaching neritic environments) but when coupled with a minimum depth of exchange (which would allow exchange <u>not</u> in the mid ocean) may set the stage for potential confusion.

Deep ocean (or deep sea) is also a general mariner's term. Canadian, U.S., and IMO/MEPC guidelines suggest that exchanges preferably take place in water depths greater than 2000 meters (6,562 feet, 1094 fathoms, 1.243 statute miles), a depth that would suggest application of the term "deep ocean". Unfortunately, such depths can occur very close to continental margins (see text), and the release of plankton at such sites may not "guarantee" that exotic species will not arrive upon the shore.

Open ocean (or open sea) as with "at sea," this term denotes no specific depth of water nor distance from land. Many mariners would describe their vessel as in the "open ocean" when on offshore fishing banks of only a few tens of meters depth, or when their vessel is within site of land.

High seas may or may not refer to that region of the ocean beyond a country's legal jurisdiction. Under current U.S. law vessels bound for the Great Lakes, and which have passed out of *either* the United States' or Canada's **exclusive economic zone** (a 200 mile [322 kilometer] distance from land) since their last port of call, are now required (with identified exemptions) to undergo exchange "on the waters beyond the EEZ, in an ocean depth of not less than 1.24 miles (2,000 meters)....". This concept has the advantage of coupling distance from shore with depth, and would thus prevent a vessel from undergoing exchange in deep water which was close to shore.

In the present report, we simply use ***Exchange (Deballast/Reballast)***, pending international discussion on the issue of terminology.

(2) If exchange occurs far enough from the continental margin, **either (a) ocean currents would take too long to transport the released organisms back to neritic waters ("too long" defined as beyond the life (or planktonic life stage) of the organisms) or (b) ocean gyres would prevent the released organisms from leaving the release site before they died.**

Exchange of water in the "middle" of ocean basins has the potential to satisfy these foundation principles. However, "mid ocean" exchange also potentially places a vessel at sites where exchange, because of sea conditions, may often be the most difficult.

Rare exceptions to these two principles can occur, but these appear to be restricted to adult organisms. Living shallow-water tropical mollusks, for example, are occasionally carried ashore in the British Isles on floating debris apparently derived from Caribbean or adjacent tropical systems. These organisms would have had to survive several months transport through the Gulf Stream and open North Atlantic waters, going from warm tropical temperatures to cold temperate waters. There are no records of such tropical species establishing populations in high northern latitudes as a result of such transport. Here we exclude, of course, those marine organisms with larvae *adapted for transoceanic transport*. These *teleplanic* larvae naturally cross the ocean, and are produced by species with generally broad distributions.

It may be noted that neither the *diversity* (numbers of species) nor the *abundance* (density of individuals per unit space) of organisms in the "open ocean" is part of the scientific foundation of exchange. While *initial ballasting up* in offshore waters decreases (to the point of virtually being non-existent) the possibility of taking in shallow-water benthic or planktonic organisms or their cysts, this is distinct from the biological principles behind the *deballasting-reballasting* process. Occasional reference is made in the ballast water exchange literature to the concept that the open ocean has fewer species, and in far fewer numbers, than inshore waters, and that this is a major reason for the potential success of exchange. The comparative diversity between inshore and offshore waters is not, however, strictly applicable to the success of the exchange process. Indeed, certain oceanic planktonic communities are far more diverse than inshore waters (the tropical plankton of the Gulf Stream or Sargasso Sea, for example, as compared to the cold-water boreal plankton of Georges Bank or the Gulf of Maine), and certain organisms in oceanic waters can be extraordinarily abundant (such as the cyanobacteria (blue-green algae) Trichodesmium (Oscillatoria)).

A number of benefits and concerns are associated with exchange as a management strategy. These are summarized in Box 6-6a and 6-6b. Among the major benefits are (1) the high probable efficacy of this method in removing and/or killing freshwater organisms, (2) the high probable efficacy of this method in reducing the numbers and diversity of neritic organisms, and (3) the present ability of most vessels to undertake some measure of exchange without any retrofitting costs. Among the chief concerns of exchange are (1) compromises to the integrity of the vessel during the exchange process, (2) costs associated with exchange as a new addition to ship operating costs, (3) the high probability of residual organisms remaining when original water is brackish or salt and (4) the low probability of washing out large accumulations of sediment (and the organisms therein) by the exchange process (sediment removal is further discussed in options 23 and 29).

Post-exchange expectations, in terms of the potential presence of remaining, original biota, and in terms of the physical-chemical conditions of the exchanged water, have been the matter of

BOX 6-6a.

POSSIBLE AND PROBABLE BENEFITS ASSOCIATED WITH SALTWATER EXCHANGE

Operational

(1) *General Applicability*: Most vessels can currently undertake some measure of exchange, by some means, without retrofitting costs. For many vessels, weather permitting, exchange can normally be completed in less time than that required for transoceanic crossings.

(2) *Part of Standard Operating Procedure:* For some vessels, the cost of operation for ballast water exchange will not be a new cost, when deballasting and reballasting already occur as part of standard operating procedures (see Box 4-2).

(3) *Costs Acceptable:* For many vessels, the overall cost of operation may be acceptable, in terms of equipment wear, fuel costs, crew time, crew fatigue, and transit delays.

Biological

(4) *Effective in Removing and Killing Freshwater Organisms:* Saltwater exchange is likely to be highly effective in removing and killing freshwater organisms.

(5) *Effective in Removing Brackish water and Saltwater Organisms:* Saltwater exchange may be very important in reducing the abundance and diversity of original water brackish and saltwater organisms.

BOX 6-6b.

CONCERNS ASSOCIATED WITH EXCHANGE

Operational

(1) *Forces upon the Ship:* The larger the vessel, the greater the potential problems relative to stresses (shear forces, bending moments) on the vessel; exchange may create an unacceptable amount of free surface area in the tanks or holds, causing exacerbated stability and stress problems; under severe sea states, many vessels will be unable to undertake any exchange.

(2) *Costs not Acceptable:* For many vessels, the overall cost of operation may be unacceptable, in terms of equipment wear, fuel costs, crew time, crew fatigue, and transit delays (for the latter, the greater the ballast capacity, the greater the time to effect exchange).

Biological

(3) *Sediment and Organisms Often Remain:* In most vessels, exchange will not free up and flush out larger sediment loads, potentially leaving large numbers of organisms remaining in the ballast.

(4) *Not Effective in Removing and Killing All Freshwater Organisms:* Saltwater exchange may not eliminate the resistant stages of many freshwater organisms.

(5) *Not Effective in Removing All Brackish water and Saltwater Organisms*: For many vessels complete exchange may always be impossible (residual water remains even after pumps lose suction), and residual organisms will remain. Thus saltwater exchange may not eliminate all original water brackish and saltwater organisms.

considerable discussion. A matrix that appeared in the first IMO discussions of the ballast management issue in 1989, and now appears in the IMO's international guidelines, identified the relative likelihood of the survival of organisms depending upon the salinities of source (discharged) versus target (receiving) waters (IMO/MEPC, Resolution 50(31) (1991)):

"PROBABILITY OF ORGANISMS SURVIVAL AND REPRODUCTION"

	DISCHARGED BALLAST		
	FW	BW	SW
RECEIVING WATER			
FW	High	Medium	Low
BW	Medium	High	High
SW	Low	High	High

FW= Freshwater; BW= Brackish water; SW = Salt water

This chart presents qualitative probabilities of organism survival, and as such sets certain expectations. The chart was originally prepared by J. T. Carlton during a coffee break at a workshop, organized and sponsored by the Great Lakes Fisheries Commission, concerning ballast water management strategies. The chart was designed to clarify certain misconceptions among non-biologists present about the relative probabilities of initial survival of organisms released into three different salinity regimes. It was presented as an overhead to the workshop as an unscheduled presentation; evidently it was copied down by some of the participants present. In the IMO guidelines it bears the heading, "Probability of Organisms Survival and Reproduction". There was no original title for this chart but, at the least, "reproduction" should be deleted from this title, as the probabilities of reproduction are dependent upon a much broader array of environmental phenomena than salt concentration. More importantly the usefulness of this chart is perhaps limited by the terms "high", "medium", and "low", which are sufficiently qualitative as to permit no clear basis for prediction or management.

A basic "exchange matrix" relative to the resulting salinity of the exchanged water and dependent on the amount (proportion) of water exchanged (partial vs. complete exchange) (Table 6-3) permits the identification of certain substitution and/or dilution expectations following exchange. *For exchange occurring in the ocean in waters of full salinity characteristic of the region in question* (Table 6-3), resulting exchanged water would be as follows:

Situation 3: For fresh water, brackish water would result as a worst case scenario. This would lead to the potential survival of certain freshwater organisms (as discussed below).

Situation 6: For brackish water, brackish water would also result as a worst case scenario. This would also lead to the potential survival of certain brackish water organisms, or some freshwater organisms living in brackish water (such as free-living adults or resting stages washed down into the estuary from up river sources).

TABLE 6 - 3

EXCHANGE MATRIX: SUBSTITUTION AND DILUTION SALINITY EXPECTATIONS

In all cases it is assumed that "Resulting Exchanged Water" in reality (Table 6-4, Salinity section, right hand column) is a combination of mixed "Original Water" and "Exchange Site" water. As discussed in the text, *there is no minimum amount of original water which, when mixed with exchange site water, "guarantees" the absence of organisms from the original ballasting site.*

	Original Water	Exchange Site	Resulting Exchanged Water
1.	Fresh	Fresh	Fresh
2.	Fresh	Brackish	Brackish to Fresh
3.	Fresh	Salt	Salt to Brackish
4.	Brackish	Fresh	Fresh to Brackish
5.	Brackish	Brackish	Brackish
6.	Brackish	Salt	Salt to Brackish
7.	Salt	Fresh	Fresh to Brackish
8.	Salt	Brackish	Brackish to Salt
9.	Salt	Salt	Salt

Where,

Salinity (total salt content) is:
(o/oo = ppt = parts per thousand)

Freshwater	=	0	--	0.5	o/oo
Brackish water	=	0.5	--	30	o/oo
Saltwater	=	30 +			o/oo

These salinity values are based upon the definitions in the Venice System of Classification of Brackish Waters (Symposium on the Classification of Brackish Waters, 1959). In the Venice System, **freshwater** is called *limnetic*. **Brackish water**, found in **estuaries**, is divided into three zones: *oligohaline* (0.5 --5 o/oo), *mesohaline* (5 -- 18 o/oo) and *polyhaline* (18 -- 30 o/oo). **Saltwater** is divided into the *euhaline* (30 -- 40 o/oo) and the *hyperhaline* (40+ o/oo), the latter often also called the **hypersaline** zone. A further distinction, which overlaps these definitions, is often made *relative to the physiological abilities of organisms to live in brackish and/or salt water.* Thus ***stenohaline*** organisms, with a narrower range of osmoregulatory abilities, are able to penetrate estuaries only down to about 25 o/oo (Carriker, 1967), whereas ***euryhaline*** organisms, with a broader range of osmoregulatory abilities and tolerance to lower salinity conditions, are typically found throughout most of the brackish water zone, with some species able to live (but not generally reproduce)in the freshwater zone.

Situation 9: For salt water, both original and exchanged salt water would be expected, with residual species from the original water potentially still remaining.

It is important to note that there is no minimum amount of original water which, when mixed with exchange site water, "guarantees" the absence of organisms from the original ballasting site. However, elimination of freshwater taxa through complete or almost complete exchange in salt water will generally occur (with exceptions noted below).

In turn, post-exchange expectations in terms of both living organisms present in exchanged water and "new" salinities can be divided into two categories: (1) the conditions potentially achievable under "ideal" conditions (defined as virtually complete exchange occurring of both water and sediments), and (2) the conditions most likely to be achieved under normal operating conditions (defined as incomplete exchange of water, and incomplete or no removal of sediments, conditions usually taking place).

Table 6-4 presents these expectations. Under complete exchange conditions no freshwater, estuarine or coastal marine species would be present in the water or sediments upon arrival at the next port of call (NPOC). Discharged freshwater organisms would die in the ocean (Coates et al. (1982) record the curious case of a bolus of freshwater organisms, probably discharged from a ship's ballast tank, being found in a juvenile fish caught at the ocean surface about 150 km southeast of Halifax). Under normal operating conditions, no obligate free-living freshwater organisms would be present (any residual organisms having been killed by any appreciable salt inputs). However, encysted freshwater species, in resting stages, may remain. Also remaining would be residual coastal estuarine and marine species (including the cysts of dinoflagellates), and, rarely, *euryhaline freshwater species* capable of rapid osmoregulatory acclimation from fresh to saline waters. Thus, Locke et al. (1993), in studies sampling vessels that had exchanged freshwater ballast from Europe with open ocean water, found euryhaline species remaining in two vessels. We refer to this latter phenomenon as the Malinska Effect, and define it here as the occurrence of a euryhaline freshwater organism surviving salt water ballast exchange with the water subsequently released into a freshwater environment (we name this effect after the M/V Malinska, a bulk carrier found to contain living euryhaline freshwater calanoid copepods, Eurytemora affinis (originally in ballast water from Antwerp), after undertaking ballast exchange in the Atlantic Ocean, and achieving a post-exchange salinity of 33 o/oo).

For vessels completing partial exchange, it is now well known, from Australian, Canadian, and U.S. studies, that residual water ***and organisms*** can occur in "exchanged" water. For example, several bulk woodchip carriers sampled in Coos Bay OR that had stated they had exchanged their original coastal water (in the floodable cargo hold water) with ocean water all contained living residual organisms in small numbers (in particular spionid polychaete larvae and certain centric diatoms) from their original ballasting sites in Japanese ports (Carlton et al. 1993). Williams et al. (1988) reported the presence of residual coastal species (but in far fewer numbers) of Japanese copepods in post-exchanged water arriving in Australia. Hallegraeff and Bolch (1992) found that of 32 ships that had claimed to have exchanged their ballast water in mid-ocean, 14 still contained "significant amounts of sediment, including dinoflagellate cysts."

Understanding the biological limitations of saltwater exchange on the survival of freshwater organisms requires further study, with larger sample sizes than those available to Locke et al. (1993) and with sampling of sediments (for resting stages) in vessels with original freshwater ballast exchanged in salt water. The biological limitations of saltwater exchange on removing

TABLE 6-4

BALLAST WATER EXCHANGE: POST-EXCHANGE EXPECTATIONS

POC = Port of Call

	Conditions Potentially Achievable Under Ideal Conditions of Complete Exchange	Conditions Most Likely to be Achieved Under Normal Operating Conditions of Partial Exchange
Living Organisms [based on exchange proceeding over depths of at least 2000 m and at the salinities indicated below]	No freshwater, brackish water, or coastal (neritic) marine species remaining in ballast water or sediments upon arrival at POC	No obligate free-living freshwater species in water or sediments upon arrival at POC ***Likely to be present:*** (1) *residual free-living individuals and cysts of coastal estuarine and marine species,* including the cysts of dinoflagellates (2) *euryhaline freshwater species* ("Malinska Effect", see text) (3) *cysts and other resting stages of freshwater organisms*
Salinity [salinities in left hand column determined on the basis of exchange proceeding over depths of at least 2000 m, and based upon values and locations shown in Figure 6-2]	Vessels exchanging water in North Pacific Ocean north of 40° N latitude: **33 o/oo +** Vessels exchanging water in Indian and Pacific Oceans: **34 o/oo +** Vessels exchanging water in Atlantic Ocean: **35 o/oo +** Vessels exchanging water in Northwest Atlantic Ocean north of 40° N latitude and west of 40° W longitude: **33 o/oo +** Vessels exchanging water in South Atlantic Ocean south of 40° S latitude: **34 o/oo +**	Post-exchange salinities will depend upon the combination of (A) salinity and quantity of unpumped or or unpumpable water remaining on board from original freshwater, brackish water and/or coastal marine sources and (B) salinity and quantity of oceanic water taken aboard in "deep ocean". (A) will dilute (B) proportionately

original saltwater ballast biota also requires further detailed studies, focused both on the water and sediments. Important parameters are the (1) extent of exchange accomplished (2) types of vessels involved, and (3) the pre-exchange *versus* post-exchange composition of the ballast biota.

Table 6-6 presents a summary of the resting stages of freshwater organisms that could potentially survive salt water exchange. A surprisingly diverse group of taxa, representing protozoans and 11 animal phyla, possess resting stages which may be capable of surviving extended saltwater immersion (although experimental data for most of these taxa are lacking). These organisms could thus be transported from foreign freshwater or estuarine sources to the U. S. in sediments or water, both to the Great Lakes and to other major freshwater corridors.

Post-exchange salinity expectations under complete exchange conditions are relative to where exchange took place. Based upon global isohaline oceanic salinity values (Figure 6-2), salinities ranging from 33 to 35 parts per thousand (o/oo) or more would characterize fully exchanged water. Indeed it would be impossible to ballast up water with lower salinities than these values in these oceanic regions (Figure 6-2). In reality, however, post-exchange salinities will depend upon the volume and the salinity of the unexchanged original water remaining aboard the vessel which will dilute the newly boarded oceanic water (see Tables 6-3 and 6-4).

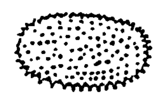
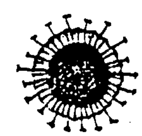
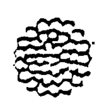
The strict application of *depth alone* as a focal point for exchange sites is limited in part by the proximity of such depths to some regions of North American continental shores, as shown in Table 6-5.

TABLE 6-5
PROXIMITY OF 2000 METER CONTOUR TO SELECTED SHORE SITES IN NORTH AMERICA

Location	Proximity of 2000 meter contour to shore: kilometers	miles
Eastern Canada		
Off Cape Harrison, Labrador	125	80
Off Cape Sable, Nova Scotia	175	110
Eastern United States		
Off Long Island, New York	175	110
Off Cape Hatteras, North Carolina	50	30
Gulf of Mexico		
Off New Orleans	250	155
Western United States		
Off Los Angeles/Long Beach	250	155
Off Point Conception	50	30
Off Straits of Juan de Fuca	125	80
Western Canada		
Off Straits of Juan de Fuca	125	80
Off Dixon Entrance (Prince Rupert)	100	60
Alaska		
Off Prince William Sound	150	95
Hawaiian Islands		
Off Honolulu	35	20

Table 6-6

FRESHWATER TAXA POTENTIALLY SURVIVING BALLAST WATER EXCHANGE IN THE FORM OF RESTING STAGES

TAXONOMIC GROUP (Common Name)	RESTING (DORMANT) AND DISSEMINULE STAGE*
Protista: "Protozoa" (protozoans)	Encystment
Porifera (sponges)	Gemmules 
Cnidaria (Coelenterata): Hydrozoa (hydroids)	Thecated embryo 
Platyhelminthes: Turbellaria (flatworms)	Encystment (eggs, cocoons)
Nemertea (Rhynchocoela) (ribbon worms)	Encystment
Nematoda (roundworms, nematodes)	Encystment
Gastrotricha (gastrotrichs)	Opsiblastic eggs 
Rotifera (rotifers, wheel animalcules)	Resting eggs (anhydrobiosis)
Bryozoa (Ectoprocta) (bryozoans)	Statoblasts (floatoblasts) 
Annelida: Oligochaeta (oligochaetes)	Encystment
Crustacea	
Ostracoda (ostracods)	Torpid eggs
Cladocera (water fleas)	Ephippia 
Conchostraca (clam shrimps)	Resting eggs
Anostraca (fairy shrimp)	Resting eggs
Copepoda (copepods)	Diapause resting eggs
Tardigrada (tardigrades)	Cryptobiotic stages and eggs  

* Not all species in these taxa possess the indicated stages

Sources: Edmondson (1959), Barnes (1987), Pennak (1989), Brusca and Brusca (1990), Thorp and Covich (1991)

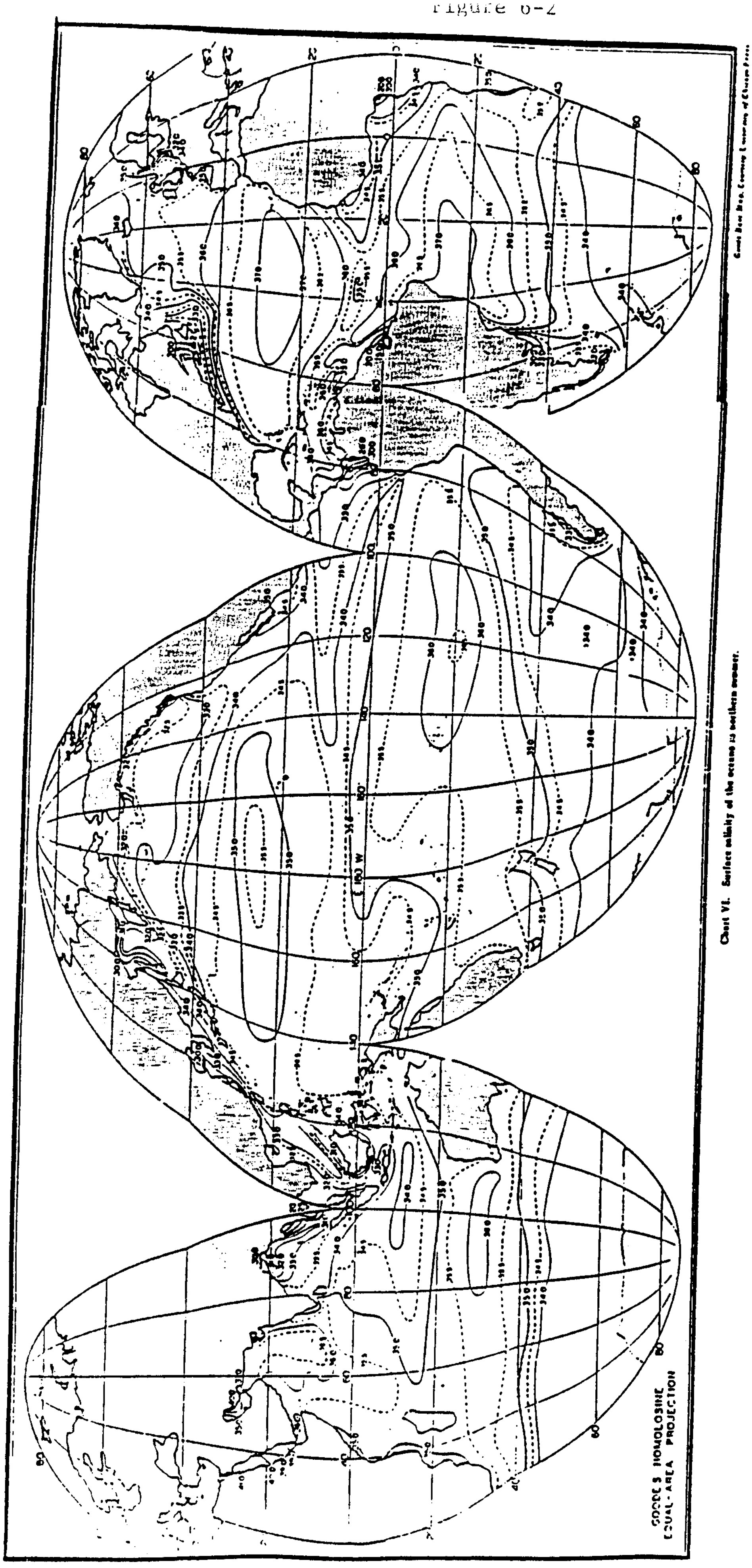


Chart VI. Surface salinity of the oceans in northern summer.

Surface salinity values of the oceans in the northern summer

From: Sverdrup, Johnson & Fleming
<u>The Oceans</u> (1947)

The release of ballast water at these and similar points relatively close to the shore may permit the survival and on-shore transport of released organisms. Thus, for example, crab or shrimp larvae, with planktonic lives of four to six weeks, during which time they may normally traverse great distances, released in large numbers at the distances shown above, may well be carried ashore (inshore). Detailed studies of hydrographic (ocean and coastal current) regimes at these *close to shore deep water sites* are required relative to the implementation of national ballast water management guidelines.

Despite the limitations noted in Box 6-6b, exchange of ballast water, coupled with ballasting micromanagement in the prevention of organism uptake (options 3-7) provide the greatest potential for reducing new biological invasions for vessels *not* undergoing refitting.

Detailed observational and experimental studies are now underway and are being planned in Australia and the United States to address the concerns listed in Box 6-6b.

Vessel stress studies have been undertaken at the University of Michigan's Department of Naval Architecture and Marine Engineering (Woodward et al., 1992). Three representative ship types were examined in detail by computer modelling: a tanker (37,575 MT ballast capacity), a dry-bulk carrier (15,952 MT capacity), and a container ship (5,209 MT capacity), under various hydrostatic conditions (stillwater changes in draft, trim, stability and hull stress as a result of ballast exchange) and under at sea conditions (changes in the seakeeping behavior). Hull bending moments and stabilities were examined to determine the tank-emptying operations that would produce the greatest changes in these parameters. Woodward et al. (1992) found that bending moment changes did not exceed, as expected, allowable still-water values. Changes in GM (gravity moment, a measure of stability) were insignificant. The worst hydrostatic cases identify those conditions that should be analyzed in rough water. Computer program results show "that in waves of 10 foot significant height wave-induced bending moments and shears are far below the design values published by the American Bureau of Shipping. On the other hand, in waves of 20-foot significant height, the maximum wave heights that occur occasionally can cause moments or shears that exceed design values" (Woodward et al., 1992). This study concluded that "ballasting/deballasting at sea can be done with safety as long as wave heights are below a maximum value. From our small sample of three ships it appears that maximum lies between 10 and 20 feet."

Rigby et al. (1993) have noted the work of M. Grey in stress fluctuations aboard a 188,200 DWT vessel, relative to displacement values in port and starboard ship sections before and during ballast exchange. Stress variations, as measured by four displacement gauges, were high, and held to be undesirable. G. Ryan (Lake Carriers' Association, personal communication, 1992) has also contracted separate studies on stress variations in Great Lakes vessels. Particular focus on vessel size has been noted by Jones (1991), who identified vessels of 40,000 DWT and above as those that would be more likely to compromise safety by undertaking exchange.

Henry (1990) noted that ballast pump alterations (such as "stronger" pumps) could reduce the exchange process time and thus increase vessel safety. In general, larger, faster, and more pumps could decrease the duration of the exchange process, and suggest a potentially fruitful area for design studies.

23. Sediment Removal and at Sea Disposal

Deep sea sediment disposal is a highly desirable offshore disposal method for neritic taxa, especially shallow-water species of toxic phytoplankton. This option involves the mechanical removal of sediments from tanks when in a deballasted state (as might occur in sequence through "open sea" ballast exchange). Limited time may be available for tank access as reballasting would under many conditions commence as soon as deballasting was completed. Access may be limited due to cargo covering tank hatches. Air quality problems may limit access to tanks as well. At sea sediment removal is a potential option given the specific circumstances for individual vessels.

Whether access is available to sediment accumulations at sea or in port (option 29), a chemical treatment option to treat sediments is in use within the maritime industry. A commercial ballast water treatment product (trade name, Mud Conditioner™; manufacturer, Drew Ameroid Marine Division, Ashland Chemical, Inc., Boonton, New Jersey) has been available for at least 12 years for sediment management (Figure 6-3). It is described by the manufacturer as follows:

> "Mud Conditioner ballast tank water treatment is a high molecular weight polymer-containing product. It is specifically designed and tested to condition mud and silt bearing ballast water, preventing dense accumulations in ballast tanks. When mixed with ballast water during ballasting operations, Mud Conditioner ballast tank water treatment reacts with the mud and silt to form large non-adhering particles. These large particles then settle quickly to the bottom of the tank but are loosely dispersed so that they can be easily discharged with the ballast water during deballasting. Mud Conditioner treatment also can be used to aid in removing existing mud accumulations in ballast tanks."

"Mud Conditioner" is diallyldi-methyl-ammonium chloride polymer with acrylamide (Chemical Abstract System number 26590-05-6). The product is a clear, viscous liquid of specific gravity 0.990 to 1.020 and a pH of 4.0 to 5.0. "Normal clean out" procedure consists of adding 15 to 40 liters (4 to 10 U.S. gallons) per 1,000 tons of ballast, with treatment repeated each time tanks are ballasted. The liquid is added during ballasting. "Rapid clean out of heavy accumulations" consists of adding 100 to 200 liters (25 to 50 gallons) per 1,000 tons of ballast water. According to product literature, "good agitation is required. Firehoses can be used to help the product penetrate mud accumulation. Leave the treatment in the tank for 3 to 5 hours, then strip it completely dry. This treatment may have to be repeated up to 5 to 8 times depending upon the severity and density of the mud accumulation".

Health risks to shipboard personnel are minimal according to product health hazard, explosion, and reactivity data sheets (MSDS), with normal chemical safety and handling precautions and methods applicable. It may be noted that under proper sediment management procedures the sediment is still *not* disposed of in the port of call.

<u>Deballasting Only</u>

24. Deballast / No Reballasting

Smaller vessels (<20,000 MT for example) may be able to deballast and proceed inbound without reballasting, especially under good weather conditions. Several such vessels reported deballasting without reballasting inbound to the Great Lakes in the lower St. Lawrence River

PRODUCT DATA

MUD CONDITIONER™
ballast tank water treatment

Drew
Ameroid
Marine

Description

MUD CONDITIONER ballast tank water treatment is a high molecular weight polymer-containing product. It is specifically designed and tested to condition mud and silt bearing ballast water, preventing dense accumulations in ballast tanks.

When mixed with ballast water during ballasting operations, MUD CONDITIONER ballast tank water treatment reacts with the mud and silt to form large non-adhering particles. These large particles then settle quickly to the bottom of the tank but a loosely dispersed so that they can be easily discharged with the ballast water during deballasting.

MUD CONDITIONER treatment also can be use to aid in removing existing mud accumulations in ballast tanks. It will minimize the expense and tim required to muck out ballast tanks prior to the application of MAGNAKOTE® rust preventative.

Features	Benefits
• Contains high molecular weight organic polymer	• Disperses heavy silt and minimizes buildup. • Maximizes cargo capacity. • Clean lines and pumping equipment. • Lower "muck out" costs. • Reduced corrosion potential.
• Concentrated liquid	• Simple application. • No dissolving. • Cost effective.
• No flash point	• No fire hazard. • Easier to use and store.

Application and Use

Normal Clean Out

The recommended level of treatment of MUD CONDITIONER treatment is 15 to 40 liters per 1,000 tons of ballast water or 4 to 10 U.S. gallons per 1,000 tons of ballast. The treatment is repeated each time tanks are ballasted.

For the most optimal results, MUD CONDITIONER ballast tank water treatment should be dosed during the course of the ballasting operations. Contact your local Drew representative to discuss the dosing equipment available from Drew Ameroid Marine.

Rapid Clean Out of Heavy Accumulations

Dose 100 to 200 liters per 1,000 tons or 25 to 50 U.S. gallons per 1,000 tons of ballast water for fast clean out of heavy mud and silt accumulations. Ad enough water to maintain 15-30 cm (6-12 inch) level in the tank. Good agitation is required. Firehoses can be used to help the product penetrat mud accumulation. Leave the treatment in the tank for 3 to 5 hours, then strip it completely dry. This treatment may have to be repeated up to 5 to 8 times depending upon the severity and density of the mud accumulation.

Typical Physical Properties

Appearance:	Clear liquid
Solubility:	Complete
Specific Gravity:	1.00 - 1.02
Stability:	Stable under normal conditions

Packaging

MUD CONDITIONER™ ballast tank water treatment is normally available in 25 to 200 liter containers (P/C#9531402 and 9531428).

Important Information

Drew maintains Material Safety Data Sheets on all of its products. Material Safety Data Sheets contain health and safety information for your development of appropriate product handling procedures to protect your employees and customers.

OUR MATERIAL SAFETY DATA SHEETS SHOULD BE READ AND UNDERSTOOD BY ALL OF YOUR SUPERVISORY PERSONNEL AND EMPLOYEES BEFORE USING DREW'S PRODUCTS IN YOUR FACILITIES.

MUD CONDITIONER ballast tank water treatment is now being used by major shipping companies as part of their regular maintenance program. It is available in the major shipping centers worldwide and is backed by individual service when and where needed. MUD CONDITIONER treatment is manufactured to the highest specifications, assuring consistent quality and performance.

Drew Ameroid Marine Division
Ashland Chemical, Inc.
Subsidiary of Ashland Oil, Inc.
One Drew Plaza
Boonton, New Jersey 07005 USA
Telephone: (201) 263-7600
Telex: 6853392 AMER ORD
Fax: (201) 263-4491

Printed in U.S.A.
MC-PD-35 (9/92)

system (D. Reid and H. van Leeuwen, personal observations, 1991). Deballasting is not exchange in the strict sense, as no new water was brought aboard. This is a potential option under limited circumstances for certain vessels.

III. BACK-UP ZONES

25. Exchange or Deballast

Vessels unable to exchange or deballast their water in the open ocean may be able to undertake ballast management in waters < 2000 meters deep or indeed upon the continental shelf. Such regions, referred to in Public Law 101-646, section 1102(a)(1)(B) as "areas within the waters of the United States and the exclusive economic zone, if any, where the exchange of ballast water does not pose a threat of infestation.....," have not been identified in U.S. waters. Current (1992) Canadian "Voluntary Guidelines for the control of ballast water discharges from ships proceeding up-river beyond Quebec City" provide (Public Law 101-646, section 4.3) for exchange in internal Canadian waters, within the Laurentian Channel (between 61 and 63 degrees West Longitude) and in water depths > 300 meters.

Back-up zones are essentially "Inshore Exchange" as compared to "Offshore Exchange" in "open ocean" water (option 22). The establishment of these zones in U.S. coastal waters will require extensive cooperation and collaboration with physical oceanographers relative to (a) microscale current and gyre regimes, such as are found offshore of large embayments, and (b) the corresponding potential (given varying seasonal, tidal, wind, and other conditions) for onshore transport and advection of offshore organisms, such that organisms (such as meroplanktonic larvae) released in ballast offshore are not carried inshore during the weeks or months of a marine invertebrate's planktotrophic life in the water column.

IV. ON ARRIVAL AT DESTINATION PORT

Water Supply: Discharge

26. Shore Facility Receives Treated and Untreated Water

This is the companion option to option (1). As such, it is not likely to be a pursuable alternative.

Prevention of Discharge to Environment

27. Discharge to Existing Sewage Treatment Facilities

Ballast water, otherwise uncontaminated with, for example, petroleum products, could be discharged directly into a city's sewage treatment facility. This option is presumably largely restricted to freshwater ballast, or ballast of extremely low salinity (< 1 o/oo), as the passage of large volumes of saltwater through a sewage plant would potentially harm or destroy the bacterial floras (and other organisms) integral to the plant organic breakdown system.

The hardware for connections from the ship to the sewage system, to deliver large volumes of freshwater to be deballasted, is unlikely to be available at most ports, nor are most such systems designed at the surface (in a fire-hydrant like matter) to receive surface water inputs. At many docking facilities in the U.S., no sewage lines lead to piers and docks. As a general

option, this alternative has further limitations relative to requirements, conditions, limitations, and costs that would be unique to virtually every port a vessel used (the same hose systems for one city may not work for the next, and so on). The widely differing abilities of sewage treatment plants to handle different volumes of water also make general considerations difficult. A possible problem would be the inadvertent introduction of exotic organisms, such as viruses, bacteria, and nematodes, from polluted ballast water into the sewage plant.

While potentially applicable on a case-by-case basis, this option is unlikely to bear further extensive development.

28. **Discharge to Lighter**

An emergency procedure, with long term development potential as standard operating procedure, involves the transfer of ballast water from the arriving vessel to a port receiving vessel. There are well-known, early precedents for this in maritime operations: oily ballast was at times "lightered off" one vessel to another to avoid harbor discharge (Arnott, 1955).

While technically not difficult (although potentially requiring the same ranges of hardware and hosing as discussed in option 27), one or more vessels would have to be dedicated to the task of ballast lightering, followed by ballast water management operations for the lighter vessel itself. In an emergency situation, a vessel found to have aboard water that would be prohibited from being discharged would either (a) go back out to an offshore ballast exchange site, exchange water, and come back into port again or (b) lighter off to another vessel that would in turn either undertake (a) itself or have more sophisticated on-board treatment options (such as filtration (with proper filtrate disposal procedures), ultraviolet, ultrasonics, or even classic sewer treatment plant approaches, such as (Gutteridge Haskins & Davey Pty Ltd., 1992) gravity settlement and flotation, pH adjustments, centrifuge/pressing of residuals, etc.) than the donating vessel. The cost effectiveness of this option (the original vessel staying in port to load cargo while the lightering vessel disposes of the water) would have to be weighed in a series of economic scenarios, and would vary dramatically by the proximity of the port to an exchange zone.

This option bears pursuit and study. A steadily growing fleet of ballast lighters over the next one to two decades, composed perhaps of vessels that had outlived their useful lives on other tracks, but which could be retrofitted for dedicated lightering, would potentially solve the "fixed receipt and treatment" problem of options 1 and 26; in short, the discharge-treatment facility could come to a vessel in question (as bunkering vessels and barges do now in many ports) rather than the vessel having to arrive at a shore ballast treatment facility at a dock different than the one for loading (or offloading) cargo. With a fixed purpose mission, a ballast lighterer could retrofit as a floating *in situ* ballast treatment plant, without compromising cargo carrying capacities or other needs.

29. **Sediment Removal and Onshore Disposal**

This option, integral to Australian, IMO, and other proposed procedures, is one of the *sine qua nons* of ballast management. It is now virtually inconceivable that ballast sediment disposal would be allowed directly into harbor or port waters. In the past, sediments brought up from tanks would frequently remain on deck until they were washed off by seawater hoses into local waters, or as the vessel proceeded outbound from the port. Rapidly growing industry awareness would now make sediment disposal in port waters tantamount to the disposal of

garbage at the same site. The availability of a chemical mud treatment has been noted in option 23.

Onshore disposal of sediments should not be substantially different than the disposal within any municipality of large volumes of soil or sand, with the exception of attention to the salt content of ballast sediments and any potential contaminants in such sediments. The expenses involved in both the *transport* of tank or hold sediment, and the *land disposal charges*, especially if many tons are involved, would appear to be the major issues involved. Given these, option (23) would likely be chosen if sediment could be retained, or held aboard, until the vessel was in ocean depths > 2000 meters (as for ballast water exchange).

Onshore sediment disposal is a pursuable option. In anticipation of this, port authorities and dry dock facilities receiving foreign vessel traffic (as well as for some domestic vessel traffic) would be advised to have land disposal/fill information, dump truck services, and costs of these, available in the same form that all other information that vessels need for sanitary ship operations is regularly available.

IMO/MEPC guidelines (Resolution 50/31 (1991), section 7.3.3) suggest as an alternative procedure sterilization of sediments "prior to being discharged into local water bodies or otherwise disposed." Except for extremely small volumes of sediments (several barrels, for example), sediment sterilization is not a likely management option, given the amounts of sediments involved (often measured in thousands of pounds).

30. In situ Extermination of Organisms Upon Arrival: Options 8, 11, and 14 Revisited

This alternative draws upon one or more of options 8, 11, and 14 *after a vessel has already arrived in port*. Emergency chemical treatment has been discussed at option 14. Filtering ballast water as it is deballasted is technically feasible; such facilities would in the future perhaps be available via a ballast lighterer with proper filtrate disposal procedures (option 28). Hand-operated UV systems, lowered into ballast tanks or holds, may have limited application in smaller tanks, but no field tests are available to demonstrate the efficacy of such mobile biocidal systems.

Active disinfection when a vessel is upon the port's doorstep is not a likely pursuable option, with the extreme exception of *in situ* chemical treatment. More probable would be to pursue options 28 (lightering) or 31 (wherein the vessel, prohibited from discharging, would be asked to return to sea or to a predefined back-up exchange zone and then come back to the port after exchanging its water).

Non-Discharge

31. Non-Discharge of Ballast Water

Non-discharge of ballast water could occur under two general situations:

(1) As a new part of general shipping operations, where a relatively large portion of the capacity of the vessel is dedicated to permanent ballast. For many, if not most, vessels this action could compromise cargo carrying capability, although some vessels currently carry some amount of permanent or semi-permanent ballast water.

(2) As a part of emergency prohibition procedures under IBM (below).

Situation (1) is not likely to be adopted; for most present-day vessels the uptake and discharge of ballast water is a required operational procedure. A cargo vessel arriving with 20,000 metric tons of seawater ballast does so with the expectation of discharging that water and loading, a similar or greater quantity of cargo. Situation (2) is achievable under classic quarantine procedures. Under these circumstances government authorities may be empowered to seal ballast valves while the vessel is in jurisdictional waters.

V. RETURN TO SEA: EXCHANGE WATER

32. Vessel Returns to Sea and Undertakes Exchange

As discussed in the section "Integrated Ballast Management," a vessel may be found to be in possession of ballast water whose discharge would be prohibited by port authorities. For some vessels this will inevitably mean an inability to load cargo (and in some cases unload cargo if ballast discharge would be used to trim the vessel). An option is for the vessel to return to sea to exchange water. This option may be the only option if (a) no onshore facilities are available to receive the water, (b) no lightering vessel is available or (c) returning to sea is less expensive than offloading ballast water to shore or to a lighter. Costs of returning to sea cannot be estimated; these would depend on the type of vessel, the amount of water, the distance the ship would be required to travel to exchange water, and many other factors (including the potential of loss of cargo to another vessel).

We were informed (during a NABISS/NV interview aboard a European-flag container ship in Savannah) that this option has been exercised with a tanker in New Zealand, but we have no details of the incident involved.

(B) CONTROL OPTIONS FOR OTHER SHIP-MEDIATED TRANSPORT MECHANISMS

A now-classic body of literature addresses the means by which vessels have controlled the development of ***fouling communities*** on their hulls and other external surfaces. J. Paul Visscher, of the Bureau of Construction and Repair of the U.S. Navy, reviewed the "state of the art" as of 1928, with particular emphasis upon experiments with antifouling paints and test panels of different colors exposed to different light regimes. In 1942 the U.S. Navy issued an annotated bibliography of 185 references published since 1930 on "Ship-Bottom Fouling and its Prevention" (Voge, 1942). The 20th century landmark on fouling was, however, the Woods Hole Oceanographic Institution's "Marine Fouling and its Prevention," completed in 1947 but not published until 1952. Two important volumes followed in the 1960s: Clapp and Kenk's massive (1136 pages) bibliography on "Marine Borers" (covering literature from the 1500s to 1954), and Turner's shipworm monograph, "A Survey and Illustrated Catalogue of the Teredinidae" (1966). Costlow and Tipper's (1984) "Marine Biodeterioration: An Interdisciplinary Study," based upon a 1981 symposium provides a useful update in many related subjects.

Outside of the U.S., activity in the late 1950s and 1960s resulted in several useful treatments. Among these are a group of 20 important papers that appeared under the title of *Morskie obrastaniya i drevotochtsy* in the Trudy Instituta Okeanologii of the Akademiia Nauk SSSR in 1961 and edited by I. V. Starostin. Included are papers by some of the leading Russian fouling biologists of the time, including N. I. Tarasov, G. B. Zevina, E. M. Lebedev, I. N. Soldatova, E. P. Turpaeva, and R. G. Simkina. This monograph was translated into English and appeared in 1968 as "Marine Fouling and Borers" (Israel Program for Scientific Translations). In 1968 the Organization for Economic Co-Operation and Development (Paris) (OECD) convened a workshop in Portsmouth, England on "Marine Borers, Fungi, and Fouling Organisms of Wood"; the proceedings were published in 1971 (Jones and Eltringham, 1971) and are a massive compilation of information. In 1963 the OECD also began publication of a useful series of handbooks, "Catalogue of Main Marine Fouling Organisms (Found on Ships Coming into European Waters)."

Thus, over 600 years of literature are available on the matter of ship fouling and boring organisms, compared to some 25 years of literature on the aquatic life in ballast water. It may thus be expected that the level of sophistication in the former field is considerably greater than in the latter field. The pattern continues at the end of the 20th century: the Eighth International Congress on Marine Corrosion and Fouling was convened in Taranto, Italy in September 1992, while a (first) "International Congress on Ballast Water and Sediments" has yet to be convened. The historical and modern-day origins of this striking dichotomy are clear: ship fouling and boring organisms historically caused and continue to cause great losses to the maritime industry, whereas ship ballast organisms have largely remained a matter of concern for biogeographers and ecologists (and only much more recently for ecologists and politicians). The vast impact of fouling and boring organisms on the evolution of the ship and on shipping in general may be appreciated by a modern calculation: Lewthwaite et al. (1985) quantified the drag imposed by an organic slime layer (a biofilm) one millimeter thick on a ship's hull. They found that this layer caused an 80 percent increase in skin friction together with a 15 percent loss in ship speed compared with values for a clean hull. Vessels that typically carry many centimeters of fouling, and 19th and earlier century vessels that had a fouling community a third of a meter or more thick on their hulls, were clearly compromised in their ability to effectively move over the oceans.

We have earlier reviewed some of the literature on ship fouling organisms, and noted that

despite the abundance of monographic literature on this subject, little is known of the extent to which fouling organisms are now transported by ships into American waters, either on their hulls or other external surfaces or in sea chests and seawater pipe systems. There is a similar dearth of information on the potential for water and sediments in anchor systems (especially the chain locker itself) to serve as a transport medium for aquatic organisms. It is clear, however, that many organisms may be transported as larvae or juveniles in ballast water and/or as adults as fouling organisms on the outside of a vessel, resulting in occasional difficulties in interpreting the exact mechanism involved which may have lead to the appearance of new nonindigenous species in U.S. coastal waters. A recent example is the appearance in the mid-1980s of the now abundant European fouling seasquirt Ascidiella on the U.S. Atlantic coast. This species may have been transported either as tadpole larvae or juveniles in ballast systems, or as a fouling organism on ships' hulls.

The modern day ***control of fouling organisms*** on vessel hulls is largely affected by the application of **antifouling** paints. Other techniques that have been or are being used include (Fischer et al., 1984) ultrasonics, electrical fields, magnetic fields, optical (UV) techniques, nuclear methods (radiation), thermal control, osmotic control, surface modifications, explosive removal, velocity control and, of course, mechanical removal (scrubbing). Some vessels may still enter freshwater intentionally to kill fouling accumulations. The leaching of heavy metals and other toxic chemicals from antifouling paints has been identified for many years as an environmental hazard. The search for alternative antifouling methods continues in the 1990s at a number of dedicated laboratories (for example, the TNO Centre for Coatings Research, Department for Corrosion and Fouling Prevention (The Netherlands), the Committee on Marine Biofouling Control of the Electrochemical Society of Japan, International Paint/Protective Coatings (UK), Xiamen Marine Test Station of Luoyang Ship Material Research Institute of the China State Shipbuilding Company (China), the Centro Studi Corrosione, Milano (Italy), the DSTO Material Research Laboratory, Victoria (Australia), and by the United States Navy and Coast Guard, and scores of other private, industry, and university laboratories). In contrast, there is no laboratory in the world dedicated to research on the control and management of ballast systems.

The ***control of sewage discharge*** from vessels is regulated by a number of international conventions and national and local laws. Virtually all vessels must now have aboard an operating sewage treatment plant or marine sanitation device. These systems are designed to produce effluent discharges at various fecal coliform densities. Chlorination is the primary chemical treatment; ultraviolet systems are used in a number of shipboard sewage treatment plants.

The ***control of sediments and organisms in anchor systems*** is achieved in part (as discussed earlier) by both manual cleaning of the anchor and anchor chain and by automatic washing as the chain passes through the hawsepipe system into the chain locker. Sediments in the chain locker are removed manually when they accumulate. As hawsepipe washing systems may be damaged or otherwise modified or simply not always entirely effective, sediments (and organisms) may regularly enter the chain locker. Most or all chain lockers have drains; these may lead to the bilge system. Such drains may become plugged and the locker may accumulate some water as well. The ability of the chain locker to support life is, however, poorly understood.

We previously reviewed the evidence that active development of antifouling mechanisms combined with changes in the shipping industry may have lead to a decrease in the transportation of organisms by some of the above mechanisms. We also reviewed evidence, however, as to why these mechanisms may still play an important role. Given this situation a study on the role of the

above mechanisms (and of others noted in Table 3-2) could prove of great value. Such a study could form the basis of the need to pursue the establishment of a National Ship Fouling Control Program and the implementation of national regulatory measures.

Chapter 7.

FEASIBILITY OF IMPLEMENTING REGIONAL VERSUS NATIONAL CONTROL MEASURES

Five areas of consideration are applicable relative to the potential implementation of regional *versus* national ballast water management measures:

(1) ***The Existence of Ballast Water Release***

(2) ***The Existence of Invasions as a Result of Ballast Water Release***

(3) ***The Ability to Predict What Species Will Invade and When and Where They Will Invade***

(4) ***The Existence of Domestic Ballast Traffic***

(5) ***The Potential Protection of Sensitive Areas***

We consider each of these below.

(1) *The Existence of Ballast Water Release*

Ballast water is released on every U.S. coastline. The types of vessels involved and the nature of their cargo suggests that ***ballast water is likely to be released in every U.S. port that receives any type of vessel delivering or taking on cargo.*** As discussed earlier, the movement and release patterns of ballast water, and subsequent secondary dispersal mechanisms, are such that no coastal sites, whether they receive direct shipping or not, are immune to ballast-mediated invasions.

The probability of invasion is determined, as elaborated earlier, by numerous factors. The role of the volume of ballast water released, one potential factor, is not yet understood in terms of the appearance of invading species. Thus, relatively small volumes of ballast water are released in the Gulf of Maine from Europe, and yet at least two marine invasions (a European seaslug and a European bryozoan) linked to ballast water appeared on the Massachusetts, New Hampshire, and Maine coastlines in the 1980s. Very large volumes of ballast water are released at New Orleans, and yet there are few reports of invasions in the Gulf of Mexico. A necessary relationship between volumes of water released and the numbers of introduced species remains elusive. (While New Orleans is a freshwater port and much of the water released there is saltwater, a large amount of saltwater must nevertheless be released in the brackish or salt regions of the Gulf region near New Orleans).

(2) *The Existence of Invasions as a Result of Ballast Water Release*

Ballast-mediated marine invasions have occurred along all U.S. coastlines (Table 5-1) with the exception of Alaska (which, however, has sustained non ballast-mediated introductions related to the Pacific commercial oyster industry). The number of invasions along these coastlines is

strikingly different, with few reports of ballast-mediated introductions on the Gulf and Hawaiian coasts, some on the Atlantic coast, and many on the Pacific coast. The significance of these distinct regional patterns, as reflective of the relative susceptibility or resistance of certain regions to invasions, is highly modified by factors (discussed elsewhere) that make it difficult to determine if the lack of reports from some regions is "real" (few invasions are occurring) or an artifact of the nature of investigations that are (or are not) conducted. Nevertheless, we have found no coastal regions of America without invasions (ballast-mediated or otherwise), and thus no coastal regions "immune" to invasions.

(3) ***The Ability to Predict What Species Will Invade and When and Where They Will Invade***

The presence of few invasions on a particular coastline, or at a particular port, or, indeed, the complete absence of invasions which cause economic or other problems at certain sites, ***offers no predictably relative to the probability of future invasions at such sites of "nuisance" ballast-released species.*** The occurrence of few ballast water invasions on a particular coastline may indicate that, compared to other regions, *fewer* invasions will continue to occur (unless there are environmental or other changes, such as the increased proximity of new exotic species), but *the number of invasions is not related to their potential severity.* It is thus not possible to predict with assurance that any region of America is less likely to sustain a new invasion with potentially large economic, ecological, or other consequences.

(4) ***The Existence of Domestic Ballast Traffic***

The existence of few invasions at certain sites in America and the existence of some regions that receive little ballast water, may nevertheless continue to foster potential thinking that control of the release of ballast water at such sites is not as critical as at other regions. However, the movement of *domestic ballast water* between hundreds of larger and smaller U.S. ports means that the potential for the concomitant movement of exotic species is very high. For example, if no ballast management regulations are in place for Port A, because it is perceived that the site is at lower risk for invasions, exotic species released at that port could be ballasted up by domestic coastal traffic and transported to Port B, where regulations may be in place. While the "front door" is being protected, the "side door" would remain open. Thus, for example, this secondary transport by *domestic* traffic has a strong potential of moving organisms established in the St. Lawrence River into the Great Lakes, of moving zebra mussels from the Great Lakes to other freshwater U.S. ports, or of moving the Asian clam from San Francisco Bay into other west coast harbors.

(5) ***The Potential Protection of Sensitive Areas***

"Sensitive" coastal regions may be broadly defined as relatively small, restricted sites where great value (environmental, social, aesthetic, economic, or otherwise) is placed on maintaining the resources as they are, and where focused disturbances could easily and radically alter those values. Examples would include (a) mariculture and aquaculture sites, (b) regions of naturally productive finfish and/or shellfish fisheries, (c) reserves and sanctuaries that attempt to preserve remaining "natural" areas from further human alteration, and (d) sites known to have rare and/or endangered marine or maritime plants and animals. Andren and Liu (1990) discuss in detail additional definitions and examples of "environmentally sensitive areas" in the sea. Hallegraeff and Bolch (1992) discuss the implications of ballast water management relative to dinoflagellate introductions and aquaculture sites.

Direct ballast release immediately adjacent to these types of regions could be prohibited. Such regulations could be part of broader policies that would prohibit the release of exotic species by any means. However, many "sensitive" areas (as defined above) are within hydrographic regimes where exotic species could be carried by domestic ballast water or naturally by currents from larger port systems (which themselves may not be considered "sensitive" areas). Because these harbors are likely sites of ballast release and thus nonindigenous species inoculations, equally high priority for ballast management would need to be applied.

We conclude that there is no location in America's shallow marine and estuarine waters, or in the freshwater rivers of America receiving ocean shipping, immune from ballast-mediated invasions. National implementation of ballast water management is indicated.

Chapter 8.

INTEGRATED BALLAST MANAGEMENT (IBM)

The IBM Program

As discussed earlier, four major approaches can be taken to ballast management: voyage, vessel, industry, and treatment (the trichotomy of "ship-board, port-based, and land-based" treatments, as proposed by Gutteridge Haskins and Davey Pty Ltd. (1992) falls within our voyage approach herein). Box 8-1 presents and arranges *selected options* for the **Vessel Approach** (based on existing/retrofit/new vessels) and **Industry Approach** and (for reference purposes) *all options* for the (type of) **Treatment Approach**.

For the Vessel Approach and the Industry Approach we have focused upon those alternatives that, based upon the above Control Options discussion, are those most likely to be pursued for further study. These are:

Prevention of Organism Intake	
Options 3-7	Ballasting Micromanagement
Removal and/or Extermination of Organisms	
Options 7 and 19	Microfiltration
Option 11	Ultraviolet Treatment
Option 12	Ultrasonics Treatment
Option 16	Thermal Treatment (more probable for *new vessel designs*)
Options 10 and 20	Altering Water Salinity
Options 23 and 29	Sediment Management
Overall Ballast Water Operations	
Option 24	Deballast/No Reballasting
Option 22	Exchange
Option 25	Back Up Zones: Deballast or Exchange
Option 28	Discharge (offload) to Reception Vessel
Option 31	Non-Discharge of Water
Option 32	Return to Sea: Deballast/No Reballasting or Exchange

In order to decrease the number of introductions in the future, a comprehensive system of ballast management could be considered. This system could be based as much as possible upon short-term pursuable options -- that is, those suitable for existing vessels. Most proposed "alternatives" or "options" are not immediately applicable to present day ships. The invocation of filtration, or heating, or other techniques, may be appropriate for vessels of the future (either retrofitted or new), but offer little immediate solution for present day shipping.

An **INTEGRATED BALLAST MANAGEMENT (IBM)** program is proposed here as a "stop-gap" management system. This Program incorporates no new technologies; it *does* incorporate new programs, such as the Global Hot Spot Program, the establishment of back-up exchange zones, and the establishment of biological monitoring laboratories. IBM is illustrated in Figure 8-1. IBM is a trichotomous program consisting of:

BOX 8-1

CONTROL OPTIONS: GROUPINGS OF SELECTED OPTIONS BY CONCEPTUAL APPROACHES
(For VOYAGE APPROACH: See Table 6-1)

VESSEL APPROACH

For existing vessels
(short term options)

Ballasting Micromanagement
A * Global Hot Spots
V * High Sediment Loads
O * Sewage Discharge
I * At Night
D
Alter Water Salinity
Exchange
Transfer to Reception Vessel
Sediment Disposal Management
Deballast/No Reballasting
Non Discharge
Return to Sea/Back Up Exchange Zones

For retrofit vessels
Issues
(long term options)

Microfiltration
Management
Ultraviolet
Ultrasonics

For new vessels
(long term options)

Microfiltration
Ultraviolet
Ultrasonics
Thermal Treatment

INDUSTRY APPROACH

Change to Standard Operating Procedure	***Economic Impact***	***Level of Human and Vessel Safety***
No change (No options)	[All options have an economic impact, but no absolute rankings are yet possible]	***Unrelated to Safety Issues*** Ballasting Micromanagement Microfiltration Non-Discharge
Moderate change Ballasting Micromanagement Alter Water Salinity Sediment Disposal Management Exchange		***Potentially Related to Safety*** Sediment Disposal Offload to Shore, Reception Vessel Ultraviolet Ultrasonics Thermal Treatment Return to Sea/BACKUP
Extensive Change Microfiltration* Ultraviolet* Ultrasonics* Transfer to Reception Vessel Non-Discharge Return to Sea/BACKUP		***Related to Safety Issues*** Exchange Ultraviolet Ultrasonics Thermal treatment

*Post-installation (on line) would lead eventually to low-to-moderate changes in SOP.

BOX 8-1

(continued)

CONTROL OPTIONS: GROUPINGS OF SELECTED OPTIONS BY CONCEPTUAL APPROACHES

TREATMENT APPROACH

Biocidal Treatments	Option	*Preventative Treatments*	Option	*Mechanical Treatments*	Option
Light: Ultraviolet Light	11, 19	Ballasting Micromanagement	3, 4, 5, 6, 7	Removal (Filtration)	8, 19
Sound: Ultrasonics	12, 19	Exchange	22, 25		
Electrical Treatment/ Microwaves	17	Deballast	24, 25		
Thermal: Increased Temperatures	16	Sediment Disposal	23, 29		
Poison: Biocidal Agents	13, 14, 15, 30	Offload to Shore, Reception Vessel	26, 27, 28		
Damage: High Water Velocity	9	Onload Treated or Fresh Water	1, 2		
Salinity: Decrease (if SW) or Increase (if FW)	10, 20	Non-Discharge	31		
Anoxia: Oxygen Deprivation	18	Return to Sea/ Back Up Exchange Zone	32		
Time: Increase Length of Voyage	21				

Figure 8-1

INTEGRATED BALLAST MANAGEMENT (IBM)

To Reduce the Risk of the Release of Nonindigenous Species

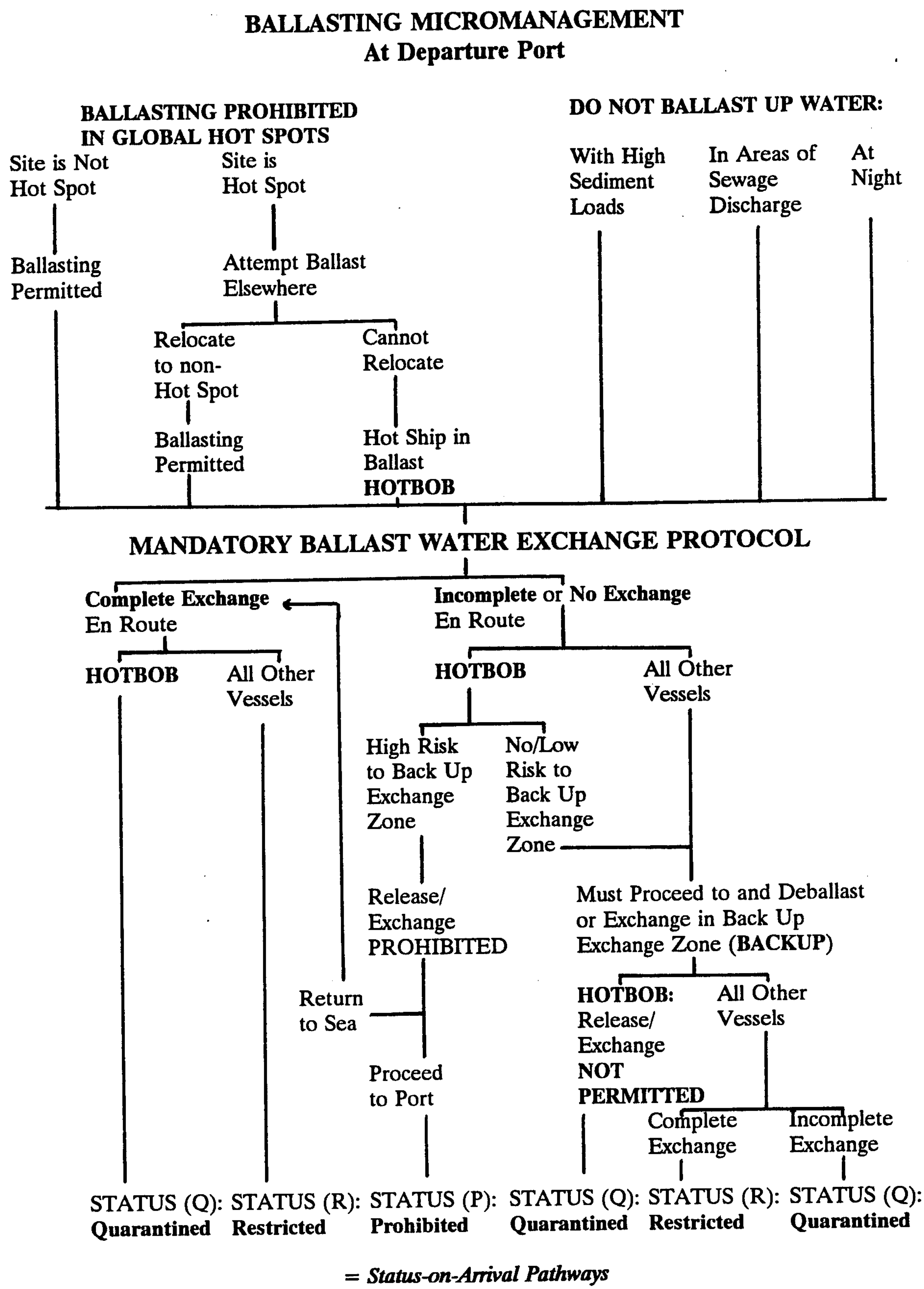


Figure 8-1 (continued)

INTEGRATED BALLAST MANAGEMENT (IBM)

To Reduce the Risk of the Release of Nonindigenous Species

STATUS-ON-ARRIVAL PATHWAYS:

STATUS:Q

Salinity (as for Status R) and Biosample Monitoring Mandatory

STATUS:R

For Vessels Originating in Freshwater

- Salinity ≥ 30 o/oo → Random Biosample
- Salinity < 30 o/oo → Biosample Mandatory

For Vessels Originating Originating in Brackish or Salt Water

- Salinity ≥ 33 o/oo → Random Biosample
- Salinity < 33 o/oo → Biosample Mandatory

Residual **HOTBOB** species *and/or* Original Freshwater Species

Residual **HOTBOB** Species *and/or* Original Estuarine -- Coastal Species

Absent → EXCHANGE SATISFACTORY → Release **PERMITTED** → STATUS: PT

Present → EXCHANGE NOT SATISFACTORY → Release **PROHIBITED** → STATUS: P

STATUS:P

> Return to **BACKUP** [unless already P in BACKUP]
or
> Return to Ocean beyond **BACKUP**
or
> Discharge to Shore or Lighter Vessel
or
> Do Not Discharge

SEDIMENT MANAGEMENT PROGRAM

* Ballasted Cargo Holds
* Ballast Tanks
* Chain Lockers

DISPOSAL IN INSHORE WATERS PROHIBITED

PERMITTED:

> *Disposal of Sediments in or Beyond BACKUP*
> *Disposal of Sediments on Shore*

(1) **Ballast Micromanagement at the Departure Port**

(2) **Ballast Water Exchange Protocols**

(3) **Ballast Sediment Management Program**

A vessel following through departure micromanagement and exchange pathways is assigned an on-arrival status in one of four categories:

Prohibited:	(P)	A vessel prohibited from discharging its ballast water
Quarantined:	(Q)	A vessel prohibited from discharging ballast until exchange status has been determined from salinity measurements and biological sampling
Restricted:	(R)	A vessel prohibited from discharging ballast until exchange status has been determined from salinity measurements and **possible** biological sampling if required
Permitted:	(PT)	A vessel permitted to discharge its ballast water

Ballasting Micromanagement

Ballasting micromanagement has been discussed in the previous section. Through a system of international and national conduits, ships' agents and port authorities advise each arriving vessel as to whether the harbor or port waters have been classed as a "Global Hot Spot" (control option 3) and why. If it is a Global Hot Spot, a vessel is advised to relocate for ballasting outside of the designated area. A Global Hot Spot Program (GHP) has not yet been established, but occurrences of certain nuisance species -- such as blooms of toxic dinoflagellates ("red tides" and other water discolorations) are likely to be known to regional fisheries authorities if not the port authorities as well. A vessel unable to relocate and that ballasts up at the Hot Spot site becomes a "hot ship in ballast" or **HOTBOB** ("hot ballast on board"). Additional micromanagement techniques are applied here as well: avoidance of waters with high sediment loads, regions of sewage discharge, and avoiding ballasting at night (options 4, 5, and 7, respectively).

Mandatory Ballast Water Exchange Protocol

None of these procedures replace the need for ballast water exchange (option 22). The locality and extent (volume) of exchange are established by examination of the vessel's "ballast log" (see *Recommendations*); severe penalties would attend falsification. Under IBM two basic types of exchange are recognized: *complete* and *incomplete/no exchange*. Under each type a HOTBOB follows separate pathways. Complete exchange is declared by the vessel as the deballasting of virtually all of the "pumpable" water from a given tank or hold, followed by reballasting. A HOTBOB undergoing complete exchange nevertheless receives an automatic Quarantine status; all other vessels are automatically placed in a Restricted status. Incomplete or no exchange encompasses all remaining vessels. A HOTBOB, depending upon the hot spot from

which it originates, may contain, or be believed to contain, organisms that are judged to be of high risk even to a back-up exchange zone (or **BACKUP**). "High risk" would be defined within the GHP system, and would include organisms which would have a probability of surviving and reproducing in the BACKUP, or of surviving for a sufficient length of time to be carried by currents in and adjacent to the BACKUP to waters where they might be able to survive. A HOTBOB not in this category, and all other vessels, would proceed to and deballast or exchange in a BACKUP (this would require, therefore, that such zones be established). A HOTBOB on this pathway receives an automatic Quarantine status; all other vessels will be determined (by vessel declaration) to have undergone either a complete or incomplete exchange in the BACKUP and receive a status of Restricted or Quarantined respectively.

All vessels on arrival in the destination port are thus either Q, R, or P (Figure 8-1). A Quarantined vessel must be sampled both for salinity (following the dichotomy for Restricted vessels, discussed next) and for the biological composition of the ballast water (a "biosample" in the IBM flow chart). Restricted vessels are also sampled for their salinity. For vessels originating in freshwater, those entering with water less than 30 o/oo would be subject to mandatory biological sampling; those with water equal to or greater than 30 o/oo would be subject to "spot checking". For vessels originating in brackish or salt water, those with water less than 33 o/oo would similarly be subject to mandatory biological sampling, and those with water greater than 33 o/oo to only "spot checking". These salinity values are based upon the discussion in the above text (see Table 6-4 and Figure 6-2). It is important to note regional exceptions around the world, such as water from the eastern Mediterranean Sea -- which can be as high as 39-40 o/oo, but could arrive *unexchanged*. In this, as in all cases, however, examination of the ship's log would reveal that exchange had not taken place.

The goal of biological sampling is to identify the presence of original freshwater, estuarine, and/or coastal organisms remaining in the water. Particular goals may include the determination of the presence of specific species from a Global Hot Spot. At this time, no "permissible" maximum densities of any organisms have been identified. If sediment is present, the presence or absence of cysts of dinoflagellates, and the exact species present, could be established. The presence or absence of other cysts of other organisms (and of course any other living organisms) could be determined as well.

Biological sampling remains one of the most difficult technological aspects under IBM. Sufficient replicated samples must be collected, in a scientific manner, from as many tanks or holds of the vessel as possible; different samples *must be collected* from tanks or holds containing different water. It is important to emphasize that adequate biological sampling cannot be accomplished by the submission of a single sample from a single tank to a contracted analytical laboratory. Sampling will typically consist of either direct use of a plankton net or of passing ballast water (via a fire hose or other outlets from identified tanks) through a sampling net (the mesh size of which would be determined depending upon the level of resolution desired). The quantity of water sampled will vary depending upon time available, method of access to the water, and the amount of water in the tank/hold system. The development of biological sampling methods and techniques is beyond the scope of this study, but it is important to note that an infrastructural system supporting the collection, analysis, and reporting upon of such samples will have to be established at some level. Dedicated state or federal laboratories will be required to process samples. It is important to *not underestimate the difficulties involved in identifying the organisms present in a sample* or *in the time it will take to process a sample*. The taxonomic expertise to identify living or preserved organisms from around the world -- ranging from the

larvae of crabs and shrimps, to copepods, to dinoflagellate cysts -- does not exist in any one institution.

In Oregon and recent Canadian studies an emphasis has been placed upon the examination of living samples. This is a *particular critical procedure* in understanding the success of ballast water exchange for freshwater and brackish water organisms. The dead bodies of such organisms, freshly killed in high salinity water, may remain floating in the tank. If collected and immediately preserved it will often be impossible to determine if such organisms were alive at the time of sampling (even with the application of vital stains).

No "simple", "non-expert", "instant", "quick" or "litmus paper" tests of the biological composition of ballast water have been established. The only approximation of such a test would be to examine a biological sample for the presence or absence of a *single target organism*, or type of organism (such as a specific species of dinoflagellate, or all dinoflagellate cysts in general). With *sufficient replicated samples* the absence of such "bioindicators" could be established within certain confidence levels. But samples without the target species will almost certainly contain other species -- identified, unidentified or unidentifiable organisms, for most of which the risk of release into the environment is simply not known. IMO/MPEC guidelines (Resolution 50/31, section 7.3.10) note that an arriving ship could have the option to "prove, by laboratory analysis, that the ballast water is acceptable." Other than "proving" that the water is abiotic (contains no life of any kind) it is difficult to conceive of a level of acceptability.

In the present reality, without a system established to handle and process biological samples, sampling would be bypassed in the pathway and only salinity measured. If exchange was not satisfactory (based upon salinities less than minimal), release would be **P**rohibited, and five options would be available: the vessel would return to the BACKUP (unless already a HOTBOB prohibited from utilizing the BACKUP), or return to the sea beyond the BACKUP to exchange or deballast, or discharge its water to shore, or discharge its water to a lighter vessel, or do not discharge. ***In reality***, discharge-to-shore or discharge-to-vessel options are not likely to be now available to most ships at most ports, and no discharge may be a non-option if cargo is to be loaded. Returning to sea to an exchange zone will, for most ships, incur an expensive alternative.

A SEDIMENT MANAGEMENT PROGRAM is identified at the bottom of Figure 8-1. As identified in IMO and Australian guidelines, sediment deposition in coastal waters would be prohibited. Sediment from ballast cargo holds, ballast tanks, and chain lockers would be disposed of in or beyond a BACKUP or onto land. For the latter, it can be presumed at this time that most port authorities do not have specialized facilities to handle such sediments, and thus sediment disposal would have to interface with standard urban landfill and waste disposal systems available. The constant, vigilant removal of sediments from tanks and holds serves two functions: one, that the sediment itself will not be disposed of improperly and two (as noted below), that sediment build-ups do not serve as a sink or source of residual organisms.

Numerous complications attend the establishment of an IBM. These pathways are replete with exceptions, novelties, deviations, peculiarities, and irregularities. By the very nature of the thousands of possible combinations of vessels, tanks, and ballast histories, IBM -- *as with all quarantine systems* -- possesses potentially numerous holes in the dike. Integral to any quarantine system is that the system is a filter, but not an absolute barrier. ***Invasions will continue no matter what type of ballast management system is implemented, now or in the future.*** A network of tens of thousands of agricultural agents and inspectors around the world has not stopped the introduction

of pest insect species. This apparent failure of the quarantine system is, however, secondary to their success -- which serves to reduce the diversity (numbers of species) and abundance (numbers of individuals) of potential colonists. In the case of ballast water, management "holes" have been discussed earlier: ships may declare that they have **no ballast on board** (NOBOB), or **unpumpable ballast**, or that they **do not intend to discharge ballast**. Vessels with "no ballast on board" in fact almost always do have ballast on board, but in quantities that are considered minuscule by industry standards (tens or hundreds of tons). "Unpumpable ballast" may contain living organisms from a previous port; new ballast pumped into these tanks or holds, and mixed with the unpumpable ballast, will of course then contain whatever residual organisms were previously present -- when the "new ballast" is pumped out, organisms from the previously "unpumpable" ballast may be released. Vessels that do not intend to discharge ballast may find themselves in a situation where deballasting is necessary although it was not anticipated -- such as the unexpected opportunity to take on more cargo, or passing under a bridge at an unusually high tide, or, indeed, even running aground on a shallow sandbar. Perhaps the largest hole in any IBM is the presence of sediment -- not simply the accountability for the disposal of the sediment, but that throughout exchange operations, sediment may remain in the system -- providing a "bank" of re-inoculation of newly ballasted water by residual species not deballasted.

Who would perform vessel monitoring and sampling? At present the United States Coast Guard, an agency largely without biological expertise, has been assigned management authority. A potentially cooperative agency is APHIS, an agency with a considerable amount of general biological expertise, and the only federal agency which boards virtually all foreign trade vessels entering port. U. S. Customs currently also collects vessel data (which are transferred to the U.S. Census Bureau for processing). A cooperative program between the USCG, APHIS, and Customs could be considered to manage the vast amount of data that would be collected and that would require processing. The Centers for Disease Control and the Food and Drug Administration could participate in establishing monitoring programs and techniques for the presence of human and other pathogens in ballast water and sediments.

The "Philosophy of Ballast Management" (Box 6-1) is that "ballast water and sediment management should seek to prevent the introduction of all organisms....". IBM seeks to insert as many "bottlenecks" as possible into the eventual biotic composition of arriving vessels. As the establishment of a full quarantine system proceeds, the imposition upon arriving traffic in terms of delays and thus costs is inevitable. A large amount of paperwork may accompany such systems. In practice and philosophy, however, the establishment of ***ballast quarantine science*** should be expected to follow standard quarantine science practices. These practices, as applied to arriving passengers by air or boat, or to agriculture, or to the cut-flower industry, are an integral part of tourism and commerce, wherein user groups in those industries understand and expect delays and, in large part, understand the consequences and risks of being discovered to be in a prohibited posture by virtue of being in possession of prohibited materials or by infestation with pest species. In the present case the analogue is being in possession of prohibited ballast water.

Chapter 9.

CONCLUSIONS, RECOMMENDATIONS, AND EPILOGUE

Relative Ranking of Vessel Dispersal Mechanisms

The relative importance of various vessel dispersal mechanisms cannot be quantified on the basis of present knowledge. No formal studies exist, for example, that have simultaneously examined the organisms <u>in</u> ballast systems and <u>on</u> the hulls of the same vessels at the same time, nor for any other mechanisms on the same vessel at the same time. (Carlton et al. (1993) refer to a Japanese woodchip carrier in Coos Bay, Oregon, where hull waterline fouling organisms (algae and barnacles) and ballast water were sampled). Subjective approaches, based in large part upon the numbers of observed invasions combined with probable transport mechanisms for each species (that is, working backward from the discovery of an invasion to its transport mechanism), suggest the categorizations shown in Box 9-1, in what is a probable relative order of importance at the close of the twentieth century. The focus in Box 9-1 is on vessel dispersal mechanisms relative to their roles as agents of transportation of nonindigenous organisms **from foreign shores to United States waters.** Some mechanisms (such as aquatic organisms in live holding wells in fishing vessels, or marine life transported long distances in fishing nets and trawls) may more often play critical roles in the movement of nonindigenous species **within United States waters.**

The transportation of aquatic nuisance species in ballast water and sediments is almost certainly the current leading mechanism of vessel-mediated dispersal mechanisms for shallow-water marine and brackish organisms in the world, and, for some regions (such as the Great Lakes), freshwater organisms as well. The dispersal of fouling and other organisms on ships' hulls and in ships' seachests (perhaps, as argued above, the modern-day equivalent of deep shipworm galleries of nineteenth century vessels) ranks as one of the top two mechanisms -- but this role is obfuscated by the potential assignment of a number of species to either fouling or ballast transport.

For an understanding of the modern-day importance of fouling communities on the outside and inside of vessels, and for an understanding of the role of the other vectors discussed here and listed in Table 3-2 and Box 9-1, scientific field studies are critically needed. In turn, these must be placed within the larger framework of the role of other mechanisms (in particular the aquaculture-mariculture industry) that bring in and release nonindigenous species to United States shores on a regular basis.

The Shipping Study: General Conclusions

1. **All modern ocean-going ships are biological islands acting as biotic conveyor belts,** transporting around the world and to the United States, on any one day, hundreds to thousands of species of plants, animals, and, potentially, human pathogens, in their ballast water and sediments, in seawater systems, and on their hulls. Numerous marine organisms have been introduced to American shores on and in ships for over four centuries, and continue to be introduced on a regular basis.

2. Theoretical and limited empirical evidence suggests that **fouling on ships' hulls and in**

BOX 9-1

RELATIVE RANKING OF VESSEL DISPERSAL MECHANISMS

1. **Ballast Water and Ballast Sediments**

   The transportation of living organisms in the water and sediments of ballasted tanks and holds

2. **Organisms on Vessel Exteriors and in Vessel Interiors with Exterior Connections**

   The transportation of attached fouling and nestling organisms on vessel hulls, rudders, and propellers, and in sea chests and seawater pipe systems, especially for vessels on limited maintenance schedules.

   2A. *Boring organisms may be (a) regionally transported in small wooden vessels from (for example) Caribbean ports to northern U.S. waters and become established in power plant thermal effluents and (b) still transported as planktonic stages by ballast water.*

3. Not able to be ranked separately within a third class with present knowledge:

   Anchor Systems (chain locker, chain, and anchor)

   The transportation of planktonic, benthic, or fouling organisms in water or sediments associated with the anchor system.

   Fishing Vessels (live wells, nets, traps, trawls)

   The transportation of aquatic organisms in and aboard fishing vessels.

   Sewage System Water

   The transportation of bacteria, viruses, and other microorganisms in a vessel's sewage system.

   Intentional Releases

   The transportation and intentional release of fish, shellfish, pets, and other organisms carried aboard ship.

4. Largely extinct global mechanisms, but perhaps extant regionally:

   Solid Ballast

   The transportation of littoral and marsh organisms in rocks, sand, and debris used as ballast.

seachests may still play an important role in the introduction of exotic species to American shores. Without any modern studies on the fouling communities of ships arriving in American ports, it is and will continue to be difficult to determine which of many introductions are due to ships' fouling or due to ships' ballast water. The role of semisubmersible exploratory drilling platforms, which have been very briefly documented to bring to America whole new suites of aquatic organisms not associated with normal shipping, remains virtually unknown.

3. **Ballast water is used by tens of thousands of ships on the world's oceans, canals, navigable rivers, and large lakes.** Ballast capacities range from hundreds of gallons to tens of millions of gallons of water. Ballast water is taken aboard ships to diminish hull stress, to provide proper stability and trim, to aid in propulsive efficiency, to aid in maneuverability, to compensate for consumption of fuel and water and to provide for operational needs. **Ballast water is an integral part of shipping operations**, as was its predecessor, ballast rock and sand, for centuries.

4. **Ballast is pumped or gravitated aboard vessels.** Coarse screens (plates) keep out large objects (wood, debris, larger fish, seaweed, etc.), but all suspended materials -- organic and inorganic -- less than one-half inch in size may be drawn in to the vessel. Large amounts of sediment (mud [clay and silt], sand, and even coarser material) are inevitably entrained and brought into the ballast tanks and holds, providing a secondary substrate and habitat for organisms or their resting stages (cysts) in which to live or be deposited. As water is ballasted and deballasted, these sediments may accumulate rather than being flushed out. Several studies have established that **ballast water and sediments are a viable habitat for hundreds of species of animals and plants.**

5. Vessels ballast, deballast, and reballast as a part of their normal operating procedure, for many reasons. Scores of types of vessels, with hundreds of unique modifications, carrying thousands of different cargoes on innumerable trade routes prohibit any simple characterization of "typical" ballast operations. **It is clear, however, that virtually all vessels -- whether with cargo ("with ballast") or without cargo ("in ballast") carry some amount of ballast water. Container ships may be particularly important in this regard, as they move water port-to-port on a constant, often daily basis.** While the amounts of water are small compared to bulk cargo ships in full ballast, even small amounts of water can carry large numbers of living organisms. Vessels may further carry water, combined or in separate tanks, from a number of different source regions simultaneously.

6. **Official records of acknowledged ballast (ships recorded as being in ballast by U.S. Customs) are minimal, with no information as to quantities, sources, or fate.** There are known relationships, although with wide variation, between the size of a vessel and the amount of water it can carry, and these relationships, when modified by a further ratio of the actual amount of water likely to be on board (versus the vessel's capacity) can be used to estimate the amount of water that a vessel may carry on an average trip. Different ratios, however, have been applied by different workers around the world, making direct comparisons difficult.

7. In addition to acknowledged water **a vast amount of cryptic ballast is transported and released around the world and to America.** Cryptic ballast is (a) unacknowledged ballast, that is, the water carried by ships with cargo, (b) "unpumpable" ballast, which, when mixed

with newly ballasted water later to be discharged, may provide another source of additional species, and (c) military vessel ballast water. Unacknowledged and military traffic ballast water and sediments remain as large holes in the "ballast dike." **There is a critical need to expand the field of data collected from arriving vessels**, a need which could be fulfilled with a one-page questionnaire to be filled out by ships' officers along with the normal Customs paperwork.

8. Combining estimates of the amount of acknowledged and unacknowledged water together, and adding estimates for the amount of water coming in at additional ports by additional types of vessels, **it is estimated that approximately 79,000,000 metric tons, or almost 21,000,000,000 gallons of ballast water, arrive in U. S. waters annually, most or all of which contains living organisms, largely in the form of plankton. This corresponds to over 2,400,000 gallons an hour.**

9. Vessels arrive in U.S. ports with water from hundreds of different "last ports of call" (LPOC). **LPOC itself is a poor predictor of the source of the ballast water; for half of all vessels in ballast, there is no ballast water on board from the LPOC.** When LPOCs are expanded to the United Nations' Food and Agriculture Organization (FAO) regions of the world's oceans, the relationship is improved, with 66 percent of all vessels in ballast having some or all of their water from a broader source region (Western Europe as opposed to a specific port, for example). Eighty-eight percent of container ships have water from their last FAO region, but only 33 percent of tankers fall into this expanded category. **The need for actual information about the source of the water on board is particularly underscored by this discovery.**

10. **There is a critical need to pay greatly increased attention to domestic ballast traffic.** The nature of the U. S. coastlines effectively means that much of the U.S. domestic ballast traffic "acts like" foreign ballast traffic in its potential to introduce nonindigenous species. Thus, for the U.S. Pacific coast, aquatic organisms transported from the U.S. Atlantic coast in ballast are *just as much a potential threat* to the ecosystems of the west coast as are organisms from Asia or the Indo-Pacific.

11. **Invasions are difficult to recognize**. Many species, even those which may have arrived with ballast in recent years, have world distribution patterns that lead most biogeographers to seek other than human mediated mechanisms as causes for cosmopolitan distributions. Many invasions may further be overlooked because of the long decline in attention to the biodiversity and biosystematics of the marine organisms on United States shorelines. **Despite this difficult foundation, as many as 57 species can be recognized as probable or possible ballast-mediated marine invasions in the United States** (with at least another 16 freshwater invasions in the Great Lakes).

12. America's "National Waterway System" and, in particular, **the Inland Waterway System, appears to be undergoing a wave of recent invasions**, perhaps related to increased barge and/or recreational vessel movements throughout America's heartland. The gateway appears to be New Orleans (an analogy may be drawn to Montreal as the gateway to the Great Lakes). No national study on these invasions has yet been undertaken.

13. **The philosophy of ballast management is as follows: Ballast water and sediment management should seek to prevent the introduction of all organisms, ranging from**

bacteria and viruses to algae, higher plants, invertebrates, fish, and all other entrained life. A variety of conceptual approaches to this management have been taken around the world. These include identifying control options and relating them to a ship's operations as it travels from one port to the next, to existing versus retrofit versus new vessels, to satisfying basic needs of the shipping industry in terms of modification of operating procedures, economics, and vessel and human safety, and to the type of treatment. **Thirty two options are considered in this study, of which approximately half are viewed as pursuable for further study. An important corollary to the philosophy of ballast management is that no one option or alternative is likely to be satisfactory, and thus it is not appropriate to single out any one alternative as "the most" likely or viable. The most powerful approach is an integrated management system. Full scale experimental studies and/or sea trials of the ballast treatments identified in the text should be considered if such treatment options are to be developed.**

14. **The concept of "ballasting micromanagement" would require the ship's officers to take an aggressive, pro-active approach by careful management of the exact place and time of ballasting.** Newly identified here is the phenomenon of **night ballasting, which has likely been important in leading to a number of global introductions.**

15. **Ballast exchange -- deballasting and reballasting -- either in waters of great depth (> 2000 meters, although these depths can occur as close as 30 miles to the U.S. mainland) or in back-up exchange zones -- when done as completely as possible, is currently viewed as one of the critical management steps.** As with all other options, however, exchange is not without a series of concerns and problems (unacceptable forces upon the deballasted ships, and the potential for exchanged water to continue to carry original organisms), but the anticipated benefits (overall reduction of the diversity and numbers of transported organisms and the general applicability to most vessels without requiring retrofit or redesign) have retained exchange as a reasonable option. End-point monitoring of exchanged water, in terms of water chemistry (salinity) or biology, is similarly a complex issue, with many practical operational and scientific questions yet to be addressed.

16. **Integrated Ballast Management (IBM)** is introduced here, consisting of a trichotomy of ballast micromanagement, ballast exchange protocols, and sediment management programs. IBM incorporates no new technologies. It would incorporate new programs, including a **GLOBAL HOT SPOT PROGRAM** (a formal international system identifying "blooms" of animals and plants), the **establishment of back-up zones** and the **establishment of biological monitoring laboratories**. Under the IBM program, vessels arriving in port would be assigned (after sampling for salinity and/or biota) one of **four statuses: prohibited, quarantined, restricted, and permitted (to deballast)**; these are defined in the text. The IBM program would apply to a **NATIONAL BALLAST WATER CONTROL PROGRAM**, and be supported by a proposed new federal agency, or by a cooperative program of several existing agencies. The release of ballast water in large volumes on all coasts, and the invasions of all coasts by exotic species, argues against solely regional control measures.

RECOMMENDATIONS

On the basis of the findings in this study, the following **Recommendations** are made:

1. **Implementation of a National Ballast Water Management Program**

   A National Ballast Water Management Program (NBWMP) could be established requiring that all vessels undergo, if possible, complete ballast water exchange and undertake sediment management practices. The NBWMP should be based upon an **Integrated Ballast Management** system. This system is based upon the use of multiple approaches to reduce the risk of introduction of nonindigenous species. The National Program could require that *all vessels*, with cargo and without cargo, undergo ballast management practices. *All vessels* could be required to maintain an industry-standardized ***Ballast Log Book.***

2. **Canadian-U.S. Cooperation: The North American Ballast Water Management Program**

   A U.S. national program could, either at its inception or eventually, become part of a unified North American Program. The confluent nature of Canadian and U.S. coastlines makes the joint and simultaneous control of ballast water desirable. The current U.S. - Canada joint guidelines for the Great Lakes serve as a cooperative model in this regard. Cooperation with Mexico should be considered, as well as with France (St. Pierre and Miquelon Islands).

3. **Full Scale Experimental and/or Sea Trials of Ballast Treatment and Other Options**

   Experimental studies, at the scale of actual ballast systems, and/or sea trials with specially retrofitted vessels, could be considered to test the pursuable options of mechanical (microfiltration), optical (ultraviolet), acoustics (ultrasonics), and other treatments. The timing of such studies is propitious given the shipping industry's attention to other new vessel requirements identified in the Oil Pollution Act (OPA) of 1990.

4. **U.S. Customs Could Expand its Data Gathering for Vessel Arrivals**

   As a stop-gap measure, *the field of data now gathered for vessel arrivals by U. S. Customs could be expanded.* Minimum additional data could include, for all vessels: vessel type, deadweight tonnage, ballast capacity, the amounts and exact sources of ballast on board, the amount of ballast normally carried when in ballast, and the amount of ballast to be discharged in the current port. A standard form, filled out by the officers, could be part of the regular Customs paperwork completed by the ship. This expansion could be accomplished by the Aquatic Nuisance Species Task Force.

5. **Greatly Increased Attention Could be Paid to Domestic Ballast Traffic**

   The nature of the U. S. coastlines, which include boreal, temperate, and tropical

waters, effectively means that *much of the U.S. domestic ballast traffic "acts like" foreign ballast traffic in its potential to introduce nonindigenous species*. Thus, for the U.S. Pacific coast, aquatic organisms transported from the U.S. Atlantic coast in ballast are *just as much a potential threat* to the ecosystems of the west coast as are organisms from Asia or the Indo-Pacific. Domestic vessel traffic could thus be considered for inclusion in the NBWMP.

6. **Ship Fouling Study**

A national study of the species composition and abundance of fouling and other organisms on ships' hulls, in ships' sea chests, and anchor systems, encompassing a broad range of vessel types, traffic patterns and port systems, could be undertaken. Such a study would serve to fill a critical gap in our knowledge base. Semisubmersible exploratory drilling platforms could be included. The full effect of the efficacy and success of the NBWMP will be difficult if not impossible to determine in the absence of an understanding of what species, *many of which may overlap with those transportable by ballast,* are arriving by non-ballast means. Coupled with this could be the encouragement (through, for example, IMO) of stronger international/national control measures to minimize the role of hull, seachest, and anchor systems as vectors for the introduction of nonindigenous species.

7. **International Foreign Trade Route and Global Changes in Shipping Study**

A critical hole in our understanding of ballast-mediated invasions is the role of changes in shipping (numbers and sizes of ships, changing speeds and changing volumes and quality of ballast water) and changes in donor ports. We have virtually no quantitative understanding of these phenomena in terms that permit us to either interpret the patterns of (and possible reasons for) previous invasions or to adequately predict the probabilities of future invasions. A study, perhaps sponsored by the IMO, could be done on the changing patterns of foreign trade routes and global changes in shipping that would provide a critical foundation and address this critical data gap.

8. **National Waterway System Study**

A national study by the scientific community of the role of barge and other vessel traffic in transporting a broad suite of nonindigenous aquatic organisms (not just zebra mussels) throughout the Inland Waterway System (IWS) could be undertaken. Evidence now suggests that a wave of invasions may be occurring throughout the IWS. Implication of the role of barge traffic remains unsupported by any study, nor is anything known about the species composition and abundance of fouling and other organisms on IWS vessels, and thus of the potential risks involved.

9. **Assessment of the Role of Military Vessels in the Transport and Release of Ballast Water**

Without an understanding of the role of domestic and foreign military vessels in the release of ballast water, effective risk reduction for the release of nonindigenous

species will be incomplete .

10. **Merchant Marine and Coast Guard Academy Education Programs**

Ballast water management could be incorporated into undergraduate and graduate training in U.S. Merchant Marine Academies, the U. S. Coast Guard Academy, and the U. S. Naval Academy. Similar training in other nation's academies could be recommended by the U.S. through the IMO, ICES, and other international organizations.

11. **Industry Education Programs**

U.S. Merchant Marine and other maritime-related personnel could have the opportunity to attend ***Ballast Management Training Seminars***, and receive certification that they have successfully completed such a course. Such courses could expose personnel to the broad issue of the role of shipping in the introduction of nonindigenous aquatic organisms to U.S. waters.

12. **International Cooperation and Global Unified Approaches**

As Australia has emphasized, *international cooperation and global unified ballast management programs will be, in the long run, the* sine qua non *of achieving fundamental control of aquatic biological invasions due to the release of ballast water and sediments.*

EPILOGUE: WHAT IS THE RISK?

More than 2,400,000 gallons of ballast water arrive every hour in coastal waters of the United States. This water comes from hundreds of ports, harbors, and estuaries from around the world. In most if not all of that water are living organisms. Despite the existence of ballast water corridors for over 100 years -- a fact that would lead to the potential conclusion that "all species that could have been introduced would be here by now" -- invasions continue. European zebra mussels and fish appear in the Great Lakes, Japanese shore crabs colonize the Atlantic coast, Venezuelan mussels appear on the jetties of Port Aransas, Chinese clams invade San Francisco Bay, and a plethora of Asian planktonic organisms become established in California, Oregon, and Washington. Outside of the United States are thousands of species on the invasion horizon which are transportable by ballast water and whose biological and ecological requirements overlap with those found in U.S. waters. Many of these species could cause severe ecological, economic, and social crises if introduced. The hourly inoculation of U. S. waters with ballast water -- indeed, of the waters of any country -- is invasion roulette. Evidence now before us indicates that new exotic species arrive in U.S. waters on a regular basis. The risk is high.

ACKNOWLEDGMENTS

We are grateful to over 500 persons with whom we spoke, wrote, and worked during the course of this study. Eighty-five **U. S. Coast Guard (USCG) and USDA/APHIS** personnel, whose names are listed in Appendix B, supported our port visits. Approximately 200 **officers and crew** facilitated our shipboard work.

Other **USCG** personnel directly involved with this study included Wendy Woods, Peter Tebeau, Richard Gaudiosi, Gerald Jenkins, Deborah Smith, Randy Helland, Jeff Beach, Claudia Gelzer, John Burton, Mike Farley, Mark McEwen, Alan Bentz, and Michael Adess. **U.S. Census Bureau** personnel who provided us with data and answered many questions over the course of the year were Adele Hilton and Norman Tague. **Sea Grant** personnel who facilitated this work included in Connecticut, Edward Monahan, Charles Nixon, Eleanor Minnick, and Norman Bender; in Oregon, Robert Malouf, the late William Wick, Carol Bailey, Joe Cone, Sandy Ridlington, and Steven Covey; in New York, Dave MacNeill and Charles O'Neill and at the National Office, Bernard Griswold.

Policy and related advice were provided by Janet Kelly, Kerry Hood, Dennis Nixon, David Cottingham, Robert Peoples, Allegra Cangelosi, Leon Cammen, James McCann, Michael Quigley, David Reid, and Sean Bercaw. For discussions on **control options, ship operations and shipping activities in general,** we thank Lissa Martinez, James Titus, Mark Kenna, Cecily Chiles, John Dragasevich, Joseph Schormann, John Woodward, Doug Nemeth, Laurent Guertin, Robert Sedat, Joe Craig, Ivan Lantz, Christopher Fay, Dana Hewson, George Ryan, Peter Johansen, Hans Nilsen, Pierre Messier, Ted Bearwood, and Charles Stuckey. We spoke on the telephone with perhaps another 50 individuals in **all branches of the maritime industry** who provided us with the answers to innumerable questions.

Our **Australian ballast** colleagues, particularly Geoff Rigby, Gustaaf Hallegraeff, Barry Munday, John Paxton, John Merton, Rob Williams, Madeleine Jones, and Patricia Hutchings, have graciously supplied unpublished and published literature and many discussions.

Other consulting scientists in the U.S. and Canada included Ladd Johnson, Greg Ruiz, Jon Geller, Rich Everett, Jody Berman, John Megahan, Patrick Baker, Chad Hewitt, Michael Graybill, Janet Hodder, Dustin Chivers, Walter Courtenay, Peter Moyle, Jeff Cordell, Richard Cutting, Roger Mann, Steve Kerr, Bernard Maurin, Arleen Navarret, David Policansky, Gregory Ruiz, Carol Secor, Jon Stanley, Theresa Stevens, Lu Eldredge, Carl Sindermann, Aaron Rosenfield, Austin Williams, Thomas Nalepa, Donald Schloesser, Timothy Carey, Andrea Locke, Ed Mills, Joe Leach, Gary Sprules, Andy Cohen, Janet Thompson, Fred Nichols, Alan Reiss, and Serge Gosselin. Another 30 or so scientists, acknowledged in the text, permitted us to use unpublished data.

A request from Elliott Norse inspired the section on the relationship between wars and biological invasions. Ellen Marsden's presentation on Integrated Pest Management at a National Audubon Society workshop in Washington, D.C. inspired our Integrated Ballast Management model. Vicke Starczak provided statistical advice. Isabel Stirling (University of Oregon Science Library), as always, provided instant FAX copies of critical literature. Paul O'Pecko and Wendy Schnur, of our Library at Mystic Seaport, answered 100s of questions and were instrumental in leading the way to critical literature.

We are particularly grateful to another 75 or so colleagues and students who allowed JTC

to suspend many obligations toward other commitments, manuscripts, and letters of recommendations during the final 90 days of this study.

Guiding and watchful spirits over the course of the study included Margaret Dochoda, who helped plant the seeds in early 1988, before the zebra mussel was discovered, that led to this study, Janet Kelly, who kept us advised of many developments of which we would have otherwise been unaware, John Chapman, who kept us advised on all levels (and read and critically commented on the entire draft of this study), and Debby Carlton, who continues to support this work after 17 years.

This Shipping Study was supported by the United States Coast Guard by pass-through funding to the National Sea Grant/Connecticut Sea Grant Program, Grant R/ES-6.

REFERENCES

Adess, M. L. 1982. Great Lakes Ballast Water Study. United States Coast Guard, Washington, D. C. Contract No. DTCG-23-81-C-30027, 12 pp., Tables, Appendices.

Allen, F. E. 1953. Distribution of marine invertebrates by ships. Austral. J. Mar. Freshwat. Res. 4: 307 - 316.

Anderson, I. 1992. End of the line for deadly stowaways? New Scientist, October 24 1992: 12-13.

Andren, L. and D. Liu. 1990. Environmentally sensitive areas and special areas under MARPOL 73/78, pp. 33-43, in: IMAS 90, The Institute of Marine Engineers International Conference, Marine Technology and the Environment, 23-25 May 1990. London.

Anonymous. 1992a. Ballast tanks at risk. Marine Engineering Review, July 1989, pp. 10-11.

Anonymous. 1992b. Minute enemies cause big problems. Marine Engineering Review, July 1989, p. 10.

Arnott, D., ed., 1955. Design and construction of steel merchant ships. Society of Naval Architects and Marine Engineers, New York, 494 pp.

Bagaveeva, E. V. 1988. Polychaetes in foulings of ships plying coasts in the northwestern part of the Sea of Japan. Soviet J Mar Biol. 14: 22-26.

Baldwin, R. P. 1992. Cargo vessel ballast water as a vector for the spread of toxic phytoplankton species to New Zealand. J. Roy. Soc. New Zealand 22:229-242.

Baltz, D. M. 1991. Introduced fish in marine systems and inland seas. Biol. Conserv. 56: 151-177.

Barnes, R. D. 1987. Invertebrate Zoology. Fifth ed. Saunders College Publ., New York, 893 pp.

Bederman, D. J. 1991. International control of marine "pollution" by exotic species. Ecology Law Quarterly 18: 677-717.

Benech, S. V. 1978. Ocean transport of a community of the grapsid crab Plagusia dentipes (de Haan, 1833). Crustaceana 35: 104.

Berman, J. and J. T. Carlton. 1991. Marine invasion processes: interactions between native and introduced marsh snails. J. Exp. Mar. Biol. Ecol. 150:267-281.

Berman, J., L. Harris, W. Lambert, M. Buttrick, and M. Dufresne. 1992. Recent invasions of the Gulf of Maine: three contrasting ecological histories. Conservation Biology 6: 435-441.

Bertness, M. D. 1984. Habitat and community modification by an introduced herbivorous snail. Ecology 65:370-381.

Bio-Environmental Services, Ltd. 1981. The presence and implication of foreign organisms in ship ballast waters discharged into the Great Lakes, vol. 1, vol. 2. Prepared by Bio-Environmental Services Ltd. for the Water Pollution Control Directorate, Environmental Protection Service, Environment Canada.

Brinkhurst, R. O. and S. R. Gelder. 1991. Annelida: Oligochaeta and Branchiobdellida, pp. 401 -435, in: Thorp, J. H. and A. P. Covich, eds. Ecology and classification of North American freshwater invertebrates. Academic Press, Inc., New York.

Bolch, C. J. and G. M. Hallegraeff. 1990. Dinoflagellate cysts in recent marine sediments from Tasmania, Australia. Bot. Marina 33:173-192.

Bourne, N. 1979. Pacific oysters, Crassostrea gigas (Thunberg). In: British Columbia and the South Pacific Islands. In Exotic Species in Mariculture, R. Mann, ed., MIT Press, Cambridge MA, 1-53.

Bourne, N. 1982. Distribution, reproduction, and growth of Manila clam, Tapes philippinarum (Adams and Reeve) in British Columbia. J. Shellfish. Res. 2:47-54.

Bowman, T. E. and J. J. Lewis. 1989. Occurrence of the calanoid copepod Eurytemora affinis (Poppe) in the Ohio River at Louisville, Kentucky. J. Crustacean Biol. 9: 83-84.

Brenchley, G. A. and J. T. Carlton. 1983. Competitive displacement of native mud snails by introduced periwinkles in the New England intertidal zone. Biol. Bull. 165:543-558.

Brusca, R. C. and G. J. Brusca. 1990. Invertebrates. Sinauer Associates, Inc., Publishers, Sunderland, MA, 922 pp.

Callahan, S. 1991. Water ballast. Ocean Navigator 41: 63-68.

Callow, M. E. 1986. Fouling algae from "in-service' ships. Bot. Mar. 29: 351-357.

Carlton, J. T. 1975. Introduced intertidal invertebrates. In: Light's Manual: Intertidal Invertebrates of the Central California Coast, R. I. Smith and J. T. Carlton, eds. 3rd ed., University of California Press, Berkeley, pp. 17-25.

Carlton, J. T. 1979a. History, biogeography, and ecology of the introduced marine and estuarine invertebrates of the Pacific coast of North America. Ph.D. dissertation, University of California, Davis, 904 pp.

Carlton, J. T. 1979b. Introduced intertidal invertebrates of San Francisco Bay. In: San Francisco Bay: The Urbanized Estuary, T. J. Conomos, ed., American Association for the Advancement of Science, Pacific Division, San Francisco, pp. 427-444.

Carlton, J. T. 1982. The historical biogeography of Littorina littorea on the Atlantic coast of North America, and implications for the interpretation of the structure of New England intertidal communities. Malacol. Rev. 15: 146.

Carlton, J. T. 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. Ocean. Mar. Biol. Ann. Rev. 23:313-371.

Carlton, J. T. 1987. Mechanisms and patterns of transoceanic marine biological invasions in the Pacific Ocean. Bull. Mar. Sci. 41:467-499.

Carlton, J. T. 1989. Man's role in changing the face of the ocean: biological invasions and implications for conservation of near-shore environments. Conserv. Biol. 3:265-273.

Carlton, J. T. 1992a. The marine biology of maritime history. The Log (Mystic Seaport Museum) 44:31-36.

Carlton, J. T. 1992b. Introduced marine and estuarine mollusks of North America: an end-of-the-20th-century perspective. J. Shellfish Res. 11(2):1-17.

Carlton, J. T. 1992c. Dispersal mechanisms of the zebra mussel Dreissena polymorpha. In: Zebra Mussels: Biology, Impacts, and Control, T. F. Nalepa and D. W. Schloesser, eds., Lewis Publishers, Inc. (CRC Press), Boca Raton, FL, pp. 677-697.

Carlton, J.T. 1992d. The dispersal of living organisms into aquatic ecosystems: the mechanisms of dispersal as mediated by aquaculture and fisheries activities. In: Dispersal of Living Organisms into Aquatic Ecosystems, A. Rosenfield and R. Mann, eds. The University of Maryland, College Park, Maryland, pp. 13-45.

Carlton, J. T. and J. W. Chapman. 1993. Criteria for the recognition of introduced species. In preparation.

Carlton, J. T., D. P. Cheney, and G. J. Vermeij, eds. 1982. Ecological effects and biogeography of an introduced marine species: the periwinkle, Littorina littorea. Abstract from a Minisymposium and Workshop, Nahant, 1981. Malacol. Rev. 15: 143-150.

Carlton, J. T. and J. B. Geller. 1993. Ecological roulette: biological invasions and the global transport of nonindigenous marine organisms. Science 261: 78-82.

Carlton, J. T. and J. Hodder. 1993. Biogeography of coastal marine organisms: experimental studies on a replica of a sixteenth century sailing vessel. Marine Biology (accepted).

Carlton, J. T. and E. W. Iverson. 1979. Biogeography and natural history of Sphaeroma walkeri Stebbing (Crustacea: Isopoda) and its introduction to San Diego Bay, California. Journal of Natural History 15: 31-48.

Carlton, J. T. and J. A. Scanlon. 1985. Progression and dispersal of an introduced alga: Codium fragile ssp. tomentosoides (Chlorophyta) on the Atlantic coast of North America. Botanica Marina 28: 155-165.

Carlton, J. T., J. K. Thompson, L. E. Schemel, and F. H. Nichols. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam Potamocorbula amurensis. I. Introduction and dispersal. Mar. Ecol. Prog. Ser. 66:81-94.

Carlton, J. T., C. L. Secor, and E. L. Mills. 1993a. Future invasions of European invertebrates into North American fresh waters: what's next? In preparation.

Carlton, J. T., A. Cohen, and M. Fountain. 1993b. War of the Aliens: The Atlantic Green Crab Carcinus maenas Invades the Northeastern Pacific Ocean. In preparation.

Carlton, J. T., J. Geller, and D. Carlton. 1993c. Taxonomic composition of Japanese ballast water released on the Pacific coast of North America. In preparation.

Carriker, M. R. 1967. Ecology of estuarine benthic invertebrates: a perspective, pp. 442-487, in G. H. Lauff, ed., Estuaries. Amer. Assoc. Adv. Sci., 757 pp.

Chapman, J. W. 1988. Invasions of the northeast Pacific by Asian and Atlantic gammaridean amphipod crustaceans, including a new species of Corophium. J. Crustacean Biol. 8: 364-382.

Chapman, J. W. and J. T. Carlton. 1991. A test of criteria for introduced species: the global invasion of the isopod Synidotea laevidorsalis (Miers, 1881). Journal of Crustacean Biology 11: 386-400.

Chapman, J. W., J. T. Carlton, H. Lee, and R. L. Steele. 1993. How prevalent are toxic marine phytoplankton blooms? In preparation.

Cheng, L. 1989. Factors limiting the distribution of Halobates species, pp. 357-362, in: J. S. Ryland and P. A. Tyler, eds., Reproduction, genetics and distribution of marine organisms. 23rd European Marine Biology Symposium. Olsen and Olsen, Fredensborg, Denmark.

Clapp, W. F. and R. Kenk. 1963. Marine borers. An annotated bibliography. Office of Naval Research, Department of the Navy, 1136 pp.

Coates, L. J., R. C. Roff and D. F. Markle. 1982. Freshwater components in the diet of the marine neustonic fish, Urophycis tenuis (Mitchell). Env. Biol. Fish. 7: 69-72.

Cooke, W. J.1975. Shallow water hydroids from Enewetak Atoll, Marshall Islands. Micronesica 11: 85-108.

Cooke, W. J. 1984. New scyphozoan records for Hawaii: Anomalorhiza shawi Light, 1921, and Thysanostoma loriferum (Ehrenberg, 1835); with notes on several other rhizostomes. Proc. Biol. Soc. Wash. 97: 583-588.

Cordell, J. R., C. A. Morgan, and C. A. Simenstad. 1992. Occurrence of the Asian calanoid copepod Pseudodiaptomus inopinus in the zooplankton of the Columbia River estuary. J. Crustacean Biol. 12: 260-269.

Costlow, J. D. and R. C. Tipper. 1984. Marine biodeterioration: an interdisciplinary study. Naval Institute Press, Annapolis MD, 384 pp.

Couper, A., ed., 1983. The Times Atlas of the Oceans. Van Nostrand Reinhold Co., New York, 272 p.

Courtenay, W. R., Jr. and J. R. Stauffer, Jr., eds. 1984. Distribution, biology, and management of exotic fishes. The Johns Hopkins University Press, 430 pp.

Cowley, J. 1990. Regulatory and environmental aspects of marine pollution, pp. 3-15, in: IMAS 90, The Institute of Marine Engineers International Conference, Marine Technology and the Environment, 23-25 May 1990. London.

Crisp, D. J. 1973. The role of the biologist in anti-fouling research, pp. 88-93, in Proc. Third International Congress on Marine Corrosion and Fouling. Northwestern Univ. Press, Evanston IL.

Critchley, A. T. 1983. Sargassum muticum: a taxonomic history including world-wide and western Pacific distributions. J. mar. biol. assoc. U.K. 63: 617-625.

Crosby, A. W. 1986. Ecological imperialism. The biological expansion of Europe, 900 - 1900. Cambridge University Press, 368 pp.

Culotta, E. 1992. Red menace in the world's oceans. Science 257: 1476-1477.

Curtis, J. B. 1985. Vessel-source oil pollution and MARPOL 73/78: an international success story? Environmental Law 15:679-710.

Cuttress, C. E. 1961. (Introduced jellyfish in Hawaii), in: M. S. Doty, Acanthophora, a possible invader of the marine flora of Hawaii. Pacific Science 15: 547 - 552.

Dalley, R. and D. J. Crisp. 1981. Conchoderma: a fouling hazard to ships underway. Marine Biol. Letters 2:141-152.

de Kerchove, R. 1961. International Maritime Dictionary. Second ed. Van Nostrand Co., Inc. Princeton, NJ.

di Castri, F., A. H.Hansen, and M.Debussche, eds. 1990. Biological invasions in Europe and the Mediterranean basin. Monographiae Biologicae 65. Kluwer Academic Publishers

Doty, M. S. Acanthophora, a possible invader of the marine flora of Hawaii. Pac. Sci. 15: 547 -552.

Dove, R. and B. Malcolm. 1980. Studies on aquatic macrophytes. Part XXXII. The 1979 Aquatic Plant Quarantine Project. Province of British Columbia, Ministry of Environment, Inventory and Engineering Branch, 47 pp. File No. 0316533.

Dove, R. and M. Wallis. 1981. Studies on aquatic macrophytes. Part XXXIV. The 1980 Aquatic Plant Quarantine Project. Province of British Columbia, Ministry of Environment, Assessment and Planning Division Bulletin 17, 31 pp. File no. 0316533.

Dove, R. and B. Taylor, 1982. Studies on aquatic macrophytes. Part XXXVI. The 1981 Aquatic Plant Quarantine Project. Province of British Columbia, Ministry of Environment, Assessment and Planning Division. [No Bulletin No., no File No., "ISSN 0228-5568] 54 pp.

Drake, J. A., H. A. Mooney, F. di Castri, R. H. Groves, J. Kruger, M. Rejmanek, and M. Williamson, eds. 1989. Ecology of biological invasions: A global perspective. SCOPE 37. John Wiley and Sons, 528 pp.

Edmondson, C. H. 1944. Incidence of fouling in Pearl Harbor. Bernice P. Bishop Museum, Occ. Papers 18, 34 pp.

Edmondson, C. H. 1951. Some Central Pacific crustaceans. Occ. Pap. B. P.Bishop Mus. 20 (13): 183.

Edmondson, C. H.1962. Xanthidae of Hawaii. Occ. Pap. B. P. Bishop Mus. 22 (13): 215-309.

Edmondson, W. T. 1959. Ward and Whipple's Fresh-Water Biology. Second ed. John Wiley and Sons, Inc., New York, 1248 pp.

Elton, C. S. 1958. The Ecology of Invasions by Animals and Plants. Methuen and Co., Ltd., London, 181 pp.

Erseus, C., J. K. Hiltunen, R. O. Brinkhurst and D. W. Schloesser. 1990. Redefinition of Tenedridilus Holmquist (Oligochaeta: Tubificidae), with description of two new species from North America. Proc. Biol. Soc. Wash. 103:839-846.

Evans, L. V. 1981. Marine algae and fouling: a review, with particular reference to ship-fouling. Bot. Mar. 24: 167-171.

Ferrari, F. D. and J. Orsi. 1984. Oithona davisae, new species, and Limnoithona sinensis (Burckhardt, 1912) (Copepoda: Oithonidae) from the Sacramento - San Joaquin Estuary, California. J. Crustacean Biol. 4:106 - 126.

Fischer, E. C., V. J. Castelli, S. D. Rodgers and H. R. Bleile. 1984. Technology for control of marine biofouling -- a review, pp. 261-299, in: J.D. Costlow and R. C. Tipper, eds., Marine biodeterioration: an interdisciplinary study. Naval Institute Press, Annapolis MD.

Fleminger, A. and S. H. Kramer. 1988. Recent introduction of an Asian estuarine copepod, Pseudodiaptomus inopinus (Copepoda: Calanoida), into southern California embayments. Mar. Biol. 98: 535-541.

Floc'h, J. Y., R. Pajot and I. Wallentinus.1991. The Japanese brown alga Undaria pinnatifida on the coast of France and its possible establishment in European waters. J. Cons. Int. Explor. Mer. 47: 379-390.

Forteath, G. N. R., G. B. Picken, R. Ralph and J. Williams. 1982. Marine growth studies on the North Sea oil platform Montrose Alpha. Mar. Ecol. Prog. Ser. 8: 61-68.

Foster, B. A. and R. C. Willan. 1979. Foreign barnacles transported to New Zealand on an oil platform. N. Z. J. Mar. Freshwat. Res. 13: 143-149.

Gallaway, B. J. and G. S. Lewbel. 1982. The ecology of petroleum platforms in the northwestern Gulf of Mexico: a community profile. USFWS, Office of Biol. Services, Washington, D.C., FWS/OBS-82/27, xiv + 92 pp.

Garcia-Garza, M. E., G. A. Rodriguez-Almarez, and T. E. Bowman. 1992. Distribution of the possum shrimp Taphromysis louisianae (Mysidacea), including new far inland records. J. Crustacean Biol. 12: 102-103.

Geoghegan, P., M. T. Mattson, J. J. Reichle, R. G. Keppel. 1992. Influence of salt front position on the occurrence of uncommon marine fishes in the Hudson River estuary. Estuaries 15: 251-254.

Griffiths, R. W., D. W. Schloesser, J. H. Leach, and W. P. Kovalak. 1991. Distribution and dispersal of the zebra mussel (Dreissena polymorpha) in the Great Lakes region. Can. J. Fish. Aquat. Sci. 48:1381-1388.

Groves, R. H. and J. J. Burdon, eds. 1986. Ecology of biological invasions: an Australian perspective. Cambridge University Press, London, 166 pp.

Gutteridge, Haskins and Davey Pty Ltd., 1991. Ballast water treatment options for the removal of marine organisms. (Abstract in:) Management of the Discharge of Ballast Water Containing Harmful Marine Organisms. Report by Australia. Marine Environment Protection Committee, International Maritime Organization, 33rd Session, London, 26-30 October 1992.

Hall, A. 1981. Copper accumulation in copper-tolerant and non-tolerant populations of the marine fouling alga, Ectocarpus siliculosus (Dillw.) Lyngbye. Bot. Mar. 24: 223-228.

Hall, A., A. H. Fielding and M. Butler. 1979. Mechanisms of copper tolerance in the marine fouling alga Ectocarpus siliculosus -- evidence for an exclusion mechanism. Mar. Biol. 54: 195-199.

Hallegraeff, G. M. 1992. Harmful algal blooms in the Australian region. Mar. Poll. Bull. 25: 186 -190.

Hallegraeff, G. M. and C. J. Bolch. 1991. Transport of toxic dinoflagellate cysts via ships' ballast water. Marine Pollution Bulletin 22:27-30.

Hallegraeff, G. M. and C. J. Bolch. 1992. Transport of diatom and dinoflagellate resting spores in ships' ballast water: implications for plankton biogeography and aquaculture. J. Plankton Res. 14: 1067-1084.

Hallegraeff, G. M., C. J. Bolch, J. Bryan and B. Koerbin. 1990. Microalgal spores in ships' ballast water: a danger to aquaculture, pp. 475-480, in: E. Graneli et al., eds., Toxic Marine Phytoplankton. Elsevier, New York.

Hallegraeff, G. M., C. Bolch, B. Koerbin and J. Bryan. 1988. Ballast water a danger to aquaculture. Australian Fisheries 47:32-34.

Hallegraeff, G. M., S. O. Stanley, C. J. Bolch and S. I. Blackburn. 1989. Gymnodinium catenatum blooms and shellfish toxicity in southern Tasmania, Australia, pp. 77-80, *in* Red Tides: Biology, Environmental Science, and Toxicology. Elsevier Publ. Co., Inc., New York.

Hallegraeff, G. M., D. A. Steffensen and R. Wetherbee. 1988. Three estuarine Australian dinoflagellates that can produce paralytic shellfish toxins. J. Plankton Res. 10:533-541.

Hallegraeff, G. M. and C. Sumner. 1986. Toxic plankton blooms affect shellfish farms. Australian Fisheries, December 1986, 4 pp.

Hamer, M. 1991. Toxic hitchhikers conquer the world's oceans. M. Hamer. New Scientist, 23 March, page 19.

Hardy, F. G. 1981. Fouling on North Sea platforms. Botanica Marina 24: 173-176.

Hay, C. H. 1990. The dispersal of sporophytes of Undaria pinnatifida by coastal shipping in New Zealand, and implications for further dispersal of Undaria in France. Br. Phycol. J. 25: 301-313.

Hebert, P. D. N., C. C. Wilson, M. H. Murdoch, and R. Lazar. 1991. Demography and ecological impacts of the invading mollusc Dreissena polymorpha. Can. J. Zool. 69: 405-409.

Helland, R. 1991. Preventing introductions of species into the Great Lakes via shipping [4 pp.], in: Yount, J. D. 1991. Ecology and management of the zebra mussel and other introduced aquatic nuisance species. EPA 600/3-91/003, 45 pp. + Appendices.

Hellen, G. 1990. Emission control for marine medium-speed engines, pp. 93-98, in: IMAS 90, The Institute of Marine Engineers International Conference, Marine Technology and the Environment, 23-25 May 1990. London.

Hengeveld, R., ed. 1989. Dynamics of biological invasions. Chapman and Hall, London, 289 pp.

Henry, J. L. 1990. Statement of James L. Henry, President of the Transportation Institute before the Committee on Environment and Public Works, U. S. Senate. Senate Hearings 101-805 on S. 2244, pp. 85-90.

Henschel, J. R. and P. A. Cook. 1990. The development of a marine fouling community in relation to the primary film of microorganisms. Biofouling 2:1-11.

Hentschel, E. 1923. Der Bewuchs an Seeschiffen. Int. Rev. Ges. Hydrobiol. Hydrograph. 11: 238 -264.

Hentschel, E. 1924. Das Werden und Vergehen des Bewuchses an Schifen. Mitt. Zool. Staat. Zool. Mus. Hamburg 41: 1-51.

Hicks, D. W. and J. W. Tunnell. 1993. Invasion of the south Texas coast by the edible brown mussel, Perna perna (Linnaeus, 1758). Veliger 36: 92-94.

Hill, A. R. 1990. Discussion of Papers 18 and 19, p. 153, in IMAS 90, The Institute of Marine Engineers International Conference, Marine Technology and the Environment, 23-25 May 1990. London.

Hoagland, K. E. 1981. Life history characteristics and physiological tolerances of Teredo bartschi, a shipworm introduced into two temperate zone nuclear power plant effluents. Proc. Third Intern. Conf. Waste Managmt. and Utilization Conference, S. S. Lee & S. Sengupta, eds., 14 pp.

Hoagland, K. E. and R. D. Turner. 1980. Range extensions of teredinids (shipworms) and polychaetes in the vicinity of a temperate-zone nuclear generating station. Mar. Biol. 58:55-64.

Hopkins, S. H. and J. D. Andrews. 1970. Rangia cuneata on the east coast: thousand mile range extension, or resurgence? Science 167:868-869.

Huang, X., W. Ni, H. Lu and K. Cui, 1979. A study on the interrelation between service condition of ships and fouling organisms. Ocean. Limnol. Sinica 10: 82-89.

Hutchings, P. 1992. Ballast water introductions of exotic marine organisms into Australia. Current status and management options. Mar. Poll. Bull. 25: 196-199.

Hutchings, P. A., J. T. van der Velde, and S. J. Keable. 1987. Guidelines for the conduct of surveys for detecting introductions of non-indigenous marine species by ballast water and other vectors -- and a review of marine introductions to Australia. Occ. Rept. Australian Museum No. 3, 147 pp.

Ichikawa, S., Y. Wakao and Y. Fukuyo. 1991. Hydrogen peroxide as an extermination agent against cysts of red tide and toxic dinoflagellates. Abstract, p. 62, in Fifth International Conference on Toxic Marine Phytoplankton, 28 October - 1 November 1991, University of Rhode Island, Narragansett, RI, USA.

ICES (International Council for the Exploration of the Sea). 1988. Recommendation of the Working Group on Introductions and Transfers of Marine Organisms of the International Council for the Exploration of the Sea (ICES), at Edinburgh, Scotland, May 31-June 3 1988. Extracted from the WG Report, ICES Mariculture Committee Document CM 1988/F:20.

International Chamber of Shipping. 1988. Discharge of ballast water loaded in algae (Chrysochromulina polyepis) infested water. [An advisory notice issued by the] International Chamber of Shipping, London, England.

Jacobson, M. K. 1953. Congeria leucophaeata(Conrad) in the Hudson River. Nautilus 66:125-127.

Joenje, W., K. Bakker, and L. Vlijm, eds. 1987. The ecology of biological invasions. Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen, volume 90, pp. 1-80.

Johnson, L. and J. T. Carlton. 1993. Human-mediated dispersal of zebra mussels (Dreissena polymorpha) into inland waters. In preparation.

Johnstone, I. M. 1986. Plant invasion windows: a time-based classification of invasion potential. Biol. Rev. 61: 369-394.

Johnstone, I. M., B. T. Coffey and C. Howard-Williams. 1985. The role of recreational boat traffic in interlake dispersal of macrophytes: a New Zealand case study. J. Environ. Management 20:263-279.

Jones, E. B. G. and S. K. Eltringham, eds. 1968. Marine borers, fungi, and fouling organisms of wood. Organization for Economic Co-Operation and Development. Paris. 367 pp.

Jones, M. M. 1991. Marine organisms transported in ballast water. A review of the Australian scientific position. Department of Primary Industries and Energy, Bureau of Rural Resources Bulletin no. 11, Australian Government Publishing Service, Canberra, 48 pp.

Jones, M. and J. Caughley. 1992. Ballast Water. Department of Primary Industries and Energy, Bureau of Rural Resources, Australian Government Publishing Service, Canberra, 16 pp.

Joska, M. A. P. and G. M. Branch. 1986. The European shore-crab -- another alien invader? African Wildlife 40:63-65.

Jude, D., R. H. Reider, and G. R. Smith. 1992. Establishment of Gobiidae in the Great Lakes Basin. Canadian Journal of Fisheries and Aquatic Sciences 49: 416-421.

Keevin, T.M., R. E. Yarbrough, and A. C. Miller. 1993. Long-distance dispersal of zebra mussels (Dreissena polymorpha) attached to hulls of commercial vessels. Dreissena polymorpha Information Review, 4: 2.

Kelly, J. 1992a. Transport of non-native organisms via cargo ship ballast discharge: characterizing the science/policy interface. Master of Marine Affairs, University of Washington, 154 pp. + Appendices.

Kelly, J. 1992b. Transport of non-native organisms in ballast sediments: an investigation of woodchip ships entering Washington State waters. Northwest Environmental Journal 8:159-160.

Koch, L. M. 1989. Mytilopsis leucophaeta (Conrad, 1831) from the Upper Mississippi River (Bivalvia: Dreissenidae). Malacology Data Net 2:153-154.

Koehn, R. K. 1991. The genetics and taxonomy of species in the genus Mytilus. Aquaculture 94: 125-145.

Kornberg, H. and M. H. Williamson, eds. 1986. Quantitative aspects of the ecology of biological invasions. Philosophical Transactions of the Royal Society of London (B, Biological Sciences), volume 314, pages 501-746.

Kott, P. 1985. The Australian Ascidiacea. Part I, Phlebobranchia and Stolidobranchia. Mem. Qd. Mus. 23: 1-440.

Kravitz, M. J. 1987. First record of Boccardiella ligerica (Ferronniere) (Polychaeta: Spionidae) from the east coast of North America. Northeast Gulf Sci. 9:39-42.

Larson, R. J. and A. C. Arneson. 1990. Two medusae new to the coast of California: Carybdea marsupialis (Linnaeus, 1758), a cubomedusa and Phyllorhiza punctata von Lendenfeld, 1884, a rhizostome scyphomedusa. Bull. So. Calif. Acad. Sci. 89:130-136.

Lewthwaite, J. C., A. F. Molland and K. W. Thomas. 1985. An investigation into the variation of ship skin frictional resistance with fouling. Trans. Roy. Inst. Naval Arch. 127: 269-284.

Lewis, J. R. and A. D. Mercer. 1984. Corrosion and marine growth on offshore structures. Ellis Horwood Ltd., Publishers, Chichester UK, 156 pp.

Locke, A., D. M. Reid, W. G. Sprules, J. T. Carlton, and H. C. van Leeuwen. 1992a. Effectiveness of mid-ocean exchange in controlling freshwater and coastal zooplankton in ballast water. Can. Tech. Rept. Fish. Aquatic Sci. no. 1822, 93 pp.

Locke, A., D. M. Reid, W. G. Sprules, H. C. van Leeuwen, and J. T. Carlton. 1992b. Final Report: Great Lakes Ballast Water Control Guidelines: Compliance and Effectiveness Study, 1991. Environmental Protection Agency Contract #R995164-01-0/05-R-00, 53 pp.

Locke, A., D. M. Reid, H. C. van Leeuwen, W. G. Sprules, and J. T. Carlton. 1993. Effectiveness of the Great Lakes ballast water guidelines: will voluntary ballast water exchange protect the Great Lakes? Manuscript.

Lloyd's Register of Shipping. 1991. Lloyd's Register of Ships. Volumes 1-3. London.

MacGinitie, G. E. 1938. Notes on the natural history of some marine animals. Amer. Midl. Nat. 19: 207-219.

Mandrak, N. E. 1989. Potential invasion of the Great Lakes by fish species associated with climatic warming. J. Great Lakes Res. 15: 306-316.

Mann, R., ed. 1979. Exotic species in mariculture. MIT Press, Cambridge MA, 363 pp.

MARAD (US Department of Transportation, Maritime Administration). 1991. Merchant fleets of the world. Oceangoing steam and motor ships of 1,000 gross tons and over as of January 1, 1991. MARAD Office of Trade Analysis and Insurance. 57 pp.

Marchand, L. J. 1946. The saber crab, Platychirograpsus typicus Rathbun, in Florida: a case of accidental dispersal. Quart. J. Florida Acad. Sci. 9: 93-100.

May, B. and J. E. Marsden. 1992. Genetic identification and implications of another invasive species of dreissenid mussel in the Great Lakes. Can. J. Fish. Aquatic Sci. 49:1501-1506.

McAden, D. C., G. N. Greene, and W. B. Baker. 1987. First record of Centropages typicus Kroyer (Copepoda: Centropagidae) in the Gulf of Mexico. Texas J. Sci. 39: 290-291.

McDermott, J. J. 1991. A breeding population of the western Pacific crab Hemigrapsus sanguineus (Crustacea: Decapoda: Grapsidae) established on the Atlantic coast of North America. Biological Bulletin 181: 195-198.

McDonald, J. H. and R. K. Koehn. 1988. The mussels Mytilus galloprovincialis and M. trossulus on the Pacific coast of North America. Mar. Biol. 99:111-118.

Medcof, J. C.1975. Living marine animals in a ship's ballast water. Proc. Natl. Shellfish. Assoc. 65: 11-22.

Meehan, B. W., J. T. Carlton, and R. Wenne. 1989. Genetic affinities of the bivalve Macoma balthica from the Pacific coast of North America: evidence for recent introduction and historical distribution. Mar. Biol. 102:235 - 241.

Meinesz, A. and B. Hesse. 1991. Introduction et invasion de l'algue tropicale Caulerpa taxifolia en Mediterranee nord-occidentale. Oceanologica Acta 14: 415-426.

Meng, L. and J.J. Orsi. 1991. Selective predation by larval striped bass on native and introduced copepods. Trans. Amer. Fisheries Society 120: 187-192.

Mills, E. L., J. H. Leach, J. T. Carlton, and C. L. Secor. 1993. Exotic species in the Great Lakes: a history of biotic crises and anthropogenic introductions. J. Great Lakes Res. 19: 1-54.

Mooney, H. A. and J. A. Drake, editors. 1986. Ecology of biological invasions of North America and Hawaii. Ecological Studies 58. Springer-Verlag, 321 pp.

Morton, B. 1977a. An estuarine bivalve (Modiolus striatulus) fouling raw water supply systems in west Bengal, India. J. Inst. Water Engin. Sci. 31: 441-453.

Morton, B. 1977b. Freshwater fouling bivalves, pp. 1-14, in: Proc. First Internatl. Corbicula Symp., Fort Worth TX.

Morton, B. 1980. Mytilopsis sallei (Recluz) (Bivalvia: Dreissenacea) recorded from Hong Kong: an introduction by Vietnamese refugees? Malacological Review 13: 90-92.

Moss, B. L., D. Tovey and P. Court. 1981. Kelps as fouling organisms on North Sea platforms. Botanica Marina 24: 207-209.

Moyle, P. 1991. Ballast water introductions. Fisheries 16: 4-6.

Nalepa, T. F. and D. W. Schloesser, eds., 1992. Zebra Mussels: Biology, Impacts, and Control. Lewis Publishers, Inc. (CRC Press), Boca Raton, FL, pp. 677-697.

Newman, W. . 1963. On the introduction of an edible Oriental shrimp (Caridea, Palaemonidae) to San Francisco Bay. Crustaceana 5: 119-132.

Nichols, F. H. and J. K. Thompson. 1985. Persistence of an introduced mudflat community in South San Francisco Bay, California. Mar. Ecol. Prog. Ser. 24:83-97.

Nichols, F. H., J. K. Thompson, and L. E. Schemel.1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam Potamocorbula amurensis. II. Displacement of a former community. Mar. Ecol. Prog. Ser. 66:95-101.

Nouse, D. 1988. 'Variable displacement' (water ballast) for racing and cruising boats? Practical Sailor 14:4-7.

Organization for Economic Co-Operation and Development. Catalogue of Main Marine Fouling Organisms (Found on Ships Coming into European Waters). Volume 1 (1963) -

Orsi, J. J., T. E. Bowman, D. C. Marelli, and A. Hutchinson. 1983. Recent introduction of the planktonic calanoid copepod Sinocalanus doerrii (Centropagidae) from mainland China to the Sacramento - San Joaquin Estuary of California. J. Plankton Res. 5:357-375.

Orsi, J. J. and T. C. Walter. 1991. Pseudodiaptomus forbesi and P. marinus (Copepoda: Calanoida), the latest copepod immigrants to California's Sacramento - San Joaquin estuary. Proc. Fourth Intern. Conf. on Copepoda. Bull. Plankton Soc. Japan, Special volume (1991): 553 - 562.

Parkman, A. 1983. History of the waterways of the Atlantic coast of the United States. National Waterways Study, U. S. Army Engineers Water Resources Support Center, Institute for Water Resources, Navigation History NWS-83-10, 142 pp.

Pennak, R. W. 1989. Freshwater invertebrates of the United States. Third ed., John-Wiley and Sons, New York.

Plotner, R. 1968. Sensor fouling on deep submergence vehicles, pp. 267-295, in Marine sciences instrumentation, Proc. Fourth Natl. ISA Marine Sci. Symp. vol. 4. Plenum, New York.

Pollard, D. A. and P. A. Hutchings. 1990a. A review of exotic marine organisms introduced to the Australian region. I. Fishes. Asian Fish. Sci. 3: 205-221.

Pollard, D. A. and P. A. Hutchings. 1990b. A review of exotic marine organisms introduced to the Australian region. II. Invertebrates and algae. Asian Fish. Sic. 3: 223-250.

Pollutech Environmental, Ltd. 1992. A review and evaluation of ballast water management and treatment options to reduce the potential for the introduction of non-native species to the Great Lakes. Prepared for the Canadian Coast Guard. Summary Report, 64 pp., Appendix A, Ballast water characterization, 46 pp. + "Appendix A -- Detailed Tables", Technical Appendix B, Ballast Water Treatment, 207 pp.

Race, M. S. 1982. Competitive displacement and predation between introduced and native mud snails. Oecologia 54:337-347.

Randall, J. E. 1987. Introductions of marine fishes to the Hawaiian Islands. Bull. Mar. Sci. 41: 490-502.

Richards, A. 1990. Muricids: a hazard to navigation? Hawaiian Shell News (Hawaiian Malacological Society), 38: 10.

Rigby, G. R., I. G. Steverson, C. J. Bolch, and G. M. Hallegraeff. 1993. The transfer and treatment of shipping ballast waters to reduce the dispersal of toxic marine dinoflagellates, in Proceedings, Fifth International Conference on Toxic Marine Phytoplankton, 28 October - 1 November 1991, University of Rhode Island, Narragansett, RI, USA.

Roos, P. J. 1979. Two stage life cycle of a Cordylophora population in the Netherlands. Hydrobiologia 62: 231-239.

Rosenfield, A. and R. Mann, eds., 1992. Dispersal of living organisms into aquatic ecosystems. Maryland Sea Grant, University of Maryland, College Park, Maryland.

Royal Institution of Naval Architects. 1991. Significant Ships of 1991. Pensord Press, Blackwood, Gwent, Wales. 120 pp. ISBN 0 903055-1-3-9

Rueness, J. 1989: Sargassum muticum and other introduced Japanese macroalgae: biological pollution of European coasts. Marine Pollution Bulletin 20(4): 173-176.

Russell, G. and O. P. Morris. 1973. Ship-fouling as an evolutionary process. pp. 719-730, in: Proc.Third International Congress Marine Corrosion and Fouling, Gaithersburg MD.

Safriel, U. N. and N. Erez. 1987. Effect of limpets on the fouling of ships in the Mediterranean. Mar. Biol. 95: 531-537.

Sakai, T. 1976. Notes from the carcinological fauna of Japan (VI). Researches on Crustacea 7: 29-40.

Sanderson, J. C. 1990. A preliminary survey of the distribution of the introduced macroalga, Undaria pinnatifida (Harvey) Suringer on the east coast of Tasmania, Australia. Bot. Mar. 33:153-157.

Sanukida, S., H. Okamoto, and M. Hitomi. 1981. On the behavior of the indicator species of marine bottom pollution. Bull. Jap. Soc. Sci. Fish. 47:863-869.

Scales, P. and A. Bryan 1979. Studies on Aquatic Macrophytes. Part XXVII. Transport of Myriophyllum spicatum fragments by boaters and assessment of the 1978 boat quarantine program. Province of British Columbia, Ministry of Environment, Water Investigations Branch, 55 pp. File No. 0316533.

Scheltema, R. S. and J. T. Carlton. 1984. Methods of dispersal among fouling organisms and possible consequences for range extension and geographical variation, pp. 127-133, in: J.D.Costlow and R.C.Tipper, eds., Marine biodeterioration: an interdisciplinary study. Naval Institute Press, Annapolis, Maryland, 384 pp.

Schormann, J. 1990. Anatomy of a ship: Description of water usages on board ocean-going ships. Paper prepared for IJC/GLFC Workshop on Exotic Species and the Shipping Industry. Toronto, Canada, March 1-2, 1990.

Schormann, J. 1990a. Discussion of Papers 18 and 19, p. 154, in IMAS 90, The Institute of Marine Engineers International Conference, Marine Technology and the Environment, 23-25 May 1990. London.

Schormann, J., J. T. Carlton and M. Dochoda. 1990. The ship as a vector in biotic invasions, pp. 147-152, in IMAS 90, The Institute of Marine Engineers International Conference, Marine Technology and the Environment, 23-25 May 1990. London.

Seapy, R. R. 1974. The introduced semelid bivalve Theora (Endopleura) lubrica in bays of southern California. Veliger 16:385-387.

Seed, R. 1992. Systematics, evolution, and distribution of mussels belonging to the genus Mytilus: an overview. Amer. Malacol. Bull. 9:123-137.

Shushkina, E. A. and E. I. Musayeva. 1990. Structure of planktic community of the Black Sea epipelagic zone and its variation caused by invasion of a new ctenophore species. Oceanology 30: 225-228.

Sindermann, C. J. 1991. Case histories of effects of transfers and introductions on marine resources: Introduction. J. Cons. int. Explor. Mer, 37: 377-378.

Skerman, T. M. 1960. Ship-fouling in New Zealand waters: a survey of marine fouling organisms from vessels of the coastal and overseas trade. New Zealand J. Sci. 3: 620-648.

Smith, T. E. and S. R. Kerr. 1992. Introduction of species transported in ships' ballast waters: the risk to Canada's marine resources. Can. Tech. Rept. Fish. Aquatic Sci. No. 1867, v + 16 pp.

Starostin, I. V., ed. 1961. Marine fouling and borers. Trans. Inst. Oceanology, 49, 279 pp. (Translated by the Israel Program for Scientific Translations, Jerusalem, 1968).

Strayer, D. L. 1991. Projected distribution of the zebra mussel, Dreissena polymorpha, in North America. Can. J. Fish. Aquatic Sci. 48:1389-1395.

Suchanek, T. H. and C. Grossman. 1971. Viability of zooplankton, pp. 61-74, in G. C. Williams et al., eds., Studies on the effects of a steam-electric generating plant in the marine environment at Northport [New York]. Marine Sciences Research Center, State University of New York, Stony Brook, Technical Report No. 9.

Suzuki, H. and K. Konno. 1970. Basic studies on the antifouling by ultrasonic waves for ship's bottom fouling communities. I. Influences of ultrasonic waves on the larvae of barnacles, Balanus amphitrite hawaiiensis and mussels, Mytilus edulis. J. Tokyo Univ. Fish. 56: 31-48.

Sverdrup, H. U., M. W. Johnson, and R. H. Fleming. 1947. The Oceans. Their Physics, Chemistry, and General Biology. Prentice-Hall, Englewood Cliffs, NJ, 1087 pp.

Symposium on the Classification of Brackish Waters. 1959. Archivio di Oceanografia e Limnologia, 11, Supplemento, 248 pp.

Thorp, J. H. and A. P. Covich, eds., 1991. Ecology and classification of North American freshwater invertebrates. Academic Press, Inc., New York, 911 pp.

Tien-hsi, T., Jenn-yu, P. and Kou-chin, H. 1987. The recovery of the fouling clam, Limnoperna fortunei Dunker from Taiwan. Bull. Malacology (Republic of China) 13: 97-100.

Turner, R. D. 1966. A survey and illustrated catalogue of the Teredinidae (Mollusca: Bivalvia). Mem. Comp. Zool. Harvard Univ., 265 pp.

Uriz, M.-J. 1990. Possible influence of trawl fishery on recent expansion in the range of Suberites tylobtusa in the southeast Atlantic, pp. 309-315, in K. Rutzler, ed., New Perspectives in Sponge Biology. Smithsonian Institution Press, Washington, D.C.

United States Coast Guard (USCG), Centers for Disease Control (CDC), and Food and Drug Administration (FDA). 1991. [Surveys of ballast water for cholera viruses and other pathogens in vessels arriving from South American into U.S. waters in 1991-1992]

van den Brink, F. W. B., G. van der Velde, and A. b. de Vaate. 1991. Amphipod invasion on the Rhine. Nature 352: 576.

Vinogradov, M. Ye., E. A. Shushkina, E. I. Musayeva, and P. Yu. Sorokin. 1989. A newly acclimated species in the Black Sea: the ctenophore Mnemiopsis leidyi (Ctenophora: Lobata). Oceanology 29: 220-224.

Visscher, J. P. 1928. Nature and extent of fouling of ships' bottoms. Bull. Bur. Fisheries 43: 193 -252.

Voge, A. L. 1942. The literature of ship-bottom fouling and its prevention including anti-fouling coatings. Technical Literature Research Group, Research Section, Bureau of Ships, Navy Department, 107 pp.

Walter, T. C. 1984. New species of Pseudodiaptomus from the Indo-Pacific, with a clarification of P. aurivilli and P. mertoni (Crustacea: Copepoda: Calanoida). Proc. Biol. Soc. Wash. 97:369-391.

Williams, R. J., F. B. Griffiths, E. J. Van der Wal, and J. Kelly. 1988. Cargo vessel ballast water as a vector for the transport of non-indigenous marine species. Estuarine and Coastal Shelf Science 26: 409-420.

Wirth, W. W. 1947. Ephydra gracilis Packard, a recent immigrant fly in Hawaii (Diptera, Ephyridae). Proc. Hawaiian Entomol. Soc. 13: 141-142.

Wolff, T. 1977. The horseshoe crab (Limulus polyphemus) in north European waters. Vidensk. Meddr. dansk naturhist. Foren. Kobenhavn 140: 39-52.

Wolfson, A., G. Van Blaricom, N. Davis, and G. S. Lewbel. 1979. The marine life of an offshore oil platform. Mar. Ecol. Prog. Ser. 1: 81-89.

Woods Hole Oceanographic Institution. 1952. Marine Fouling and its Prevention. United States Naval Institute, Annapolis MD, 388 pp.

Woodward, J. B., M. G. Parsons, and A. W. Troesch. 1992. Ship operational and safety aspects of ballast water exchange at sea. Michigan College Sea Grant Program, Grant NA-16R-C0417-01. Final Report, 25 pp.

Yount, J. D. 1991. Ecology and management of the zebra mussel and other introduced aquatic nuisance species. EPA 600/3-91/003, 45 pp. + Appendices.

Zibrowius, H. 1979. Serpulidae (Annelida Polychaeta) de l'Ocean Indien arrives sur des coques de bateaux a Toulon (France, Mediterranee). Rapp. Comm. Internatl. Mer Medit. 25/26: 4.

Zibrowius, H. 1983. Extension de l'aire de repartition favorisee par l'homme chez les invertebres marins. Oceanis 9: 337-353.

Zibrowius, H. 1992. Ongoing modification of the Mediterranean marine fauna and flora by the establishment of exotic species. Mesogee 51: 83-107.

APPENDIX A

ACRONYMS

* See Table 3-1 for ***VESSEL*** acronyms
* See Table 4-1 for ***BALLAST TANK*** acronyms

ACK	Acknowledged
ACV	Atlantic Class Vessel (container ship)
ADM	Alternative dispersal mechanism
AKA	Also known as
ALLBOB	All Ballast Water on Board
APHIS	Animal and Plant Health Inspection Service (USDA)
AQIS	Australian Quarantine & Inspection Service
ARR	Arrival
ASP	Amnesic Shellfish Poison
AVG	Average
BAL	In ballast
BAL CAP	Ballast Water Capacity
BM	Ballast management
BMS	Ballast management strategy
BOB	Ballast water on board
BOPS	Ballast Water Operations (aboard vessels)
BT	Ballast
BUEZO	Back up Exchange Zone
BULK	Bulker
BW	Ballast water
BWARR	Ballast water carried on arrival (PPOC) in metric tons = **BOB**
BWBT	Average amount of BW carried when in ballast
BWCAP	Ballast water capacity in metric tons (may also be measured in LT, gallons)
BWE	Ballast water exchange
BWUP	Ballast Water Remaining in the Ballast Tanks: Unpumpable Water
C	Celsius degrees
CCG	Canadian Coast Guard
CDC	Centers of Disease Control
CI	Confidence interval
CONT	Container Ship
COTP	Captain Of The Port
CuM	Cubic meters
DEP	Departure
DPC	District Port Code (U. S. Census Bureau)
DSP	Diarrhetic Shellfish Poison
DWT	Dead weight tons (tonnage)
ECAREG	Eastern CAnadian REGion
ENSO	El Nino Southern Oscillation

EST	Estimated
FAO	United Nations Food and Agriculture Organization
FDA	Food and Drug Administration
FOR	Foreign
FREQ	Frequency
FW	Fresh Water
Gen	General
GHP	Global Hot Spot Program
GM	Gravity Moment (stability measure)
GRT	Gross Registered Tonnage
HAB	Harmful Algal Blooms
HOTBOB	Hot ship in or with ballast (Ballast on Board)
ICES	International Council for the Exploration of the Sea
ICS	International Chamber of Shipping
IMO	International Maritime Organization (United Nations)
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IWS	Inland Waterway System
LASH	Lighter Aboard SHip (Barge Carrier)
LPOC	Last Port of Call
LR	Lloyd's Register
LT	Long Tons
MARAD	Maritime Administration
MARPOL	UN/IMO Marine Pollution (convention)
MEPC	Marine Environment Protection Committee (IMO)
MRT	Metric revenue ton
MSO	Marine Safety Office (USCG)
MthMax	Monthly Maximum of BW carried in the Past Month
MthMin	Monthly Minimum of BW carried in the Past Month
MT	Metric Tons
M/V	Motor vessel
MW	Megawatt
N	Number
NA	Not applicable
NABISS	National Biological Invasions Shipping Study
NBWCP	National Ballast Water Control Program (Public Law 101-646)
NBWMP	National Ballast Water Management Program (Proposed Herein)
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NOBOB	No Ballast on Board
NP #	NABISS Port Number
NPOC	Next Port of Call
NRT	Net Registered Tonnage
NSP	Neurological Shellfish Poison

NV #	NABISS Vessel Number
NWS	National Waterway System
OIC	Officer In Charge (APHIS)
OPA	Oil Pollution Act of 1990
P	Prohibited Status
PAHO	Pan American Health Organization
PASS	Passenger Ship
PICES	Pacific International Council for the Exploration of the Sea
POC	Port of Cal
PPOC	Present Port of Call
PPQ	Plant Protection & Quarantine
PSP	Paralytic Shellfish Poison
PT	Permitted Status
Q	Quarantine Status
R	Restricted Status
R&D	Research and Development
RORO	Roll-on Roll-off Cargo Vessel
R/V	Research Vessel
S	Starboard
SD	Standard deviation
SDWT	Summer Deadweight Tonnage
SEDP	Semisubmersible Exploratory Drilling Platform
SLSA	St. Lawrence Seaway Authority
SOBOB	Some Ballast Water on Board
SOP	Standard operating procedure
SW	Salt Water
TANK	Tanker
TEU	Twenty-foot equivalent unit
TM	Transport Monthly
UN	United Nations
UNACK	Unacknowledged Ballast
UNEP	United Nations Environmental Program
UNESCO	United Nations Educational, Scientific, and Cultural Organization
U.S.	United States
USCG	United States Coast Guard
USDA	United States Department of Agriculture
UV	Ultraviolet (UVB, UVC)
W	Watt
WCP	West coast ports
WHO	World Health Organization
WHOI	Woods Hole Oceanographic Institution

APPENDIX B
SUMMARY OF NABISS PORT VISITS

Date	Port	Contacts
1/22/92	Boston	USCG/MSO MKC (Chief) Dan Bartlett Lt. Comm. Larry Bowling (Port Operations)
1/29/92 [see 6/1/92 for boardings]	Boston	USCG/MSO MKC (Chief) Dan Bartlett US Customs Dick Longs (Assistant Chief Inspector) Brian Lopez (Inspector) Peter Ryan (Inspector at docks) Massport Gretchin Sheehan Lyn Vikesland Boston Shipping Assoc.(Maritime Assoc.) Jody Bartlett (Administrative Assistant)
2/6-7/92	New York/ New Jersey	USCG/COTP Kelly English (Waterways Management) Steve Whinham (Waterways Mgmt) Maritime Association of New York/New Jersey Joyce McIlroy (Marine Intelligence) Port Authority Paul Druckenmiller (Port/Market Analysis) US Customs Newark Paul Russo (Inspector, Marine Desk) US Customs New York Inspector Jung (Marine Desk, Data Analysis Unit)
3/23/92	Norfolk	USCG/MSO Chief Brickett (Foreign Vessel Ops) Lt. Comm. Cummins (Port Operations) Vessels Boarded NV1) Ever General - Container NV2) Maria Auxiliadora-Container NV3) Sea Merchant - Container NV4) Feax-Bulker (Collier)
3/25/92	Baltimore	USCG/MSO Lt. Cyndi Stowe (Port Operations) Gary Merrick (Port Safety) APHIS Inspector Steve Trostle

		Vessels Boarded NV5)Fidestar-Bulker NV6)Georgia S-Bulker NV7)Eagle-OBO NV8)Seijen-RoRo(Cars) NV9)Nosac Clipper-RoRo(Cars)
4/27/92	Charleston	USCG/MSO Chief Wade Gilpin Petty Officer Rob Shier Vessels Boarded NV10)Marchen Maersk-Container NV11)Sealift Aectic-Tanker NV12)Exxon Charleston-Tanker NV13)Cristoforo Columbo-Container
4/27/92	Savannah	USCG/MSO Chief Don Pack Lieutenant Keith Fordham Chief Dan Walsh APHIS Assistant Officer in Charge David Holman Vessels Boarded NV14)Constantinous M-Bulker NV15)Clipper Atlantic-Bulker NV16)Cape May-Container NV17)Contship Brave-Container NV18)Alabama Rainbow-Bulker
5/30/92	Tampa	USCG/MSO Lieutenant Steve Metreck Lieutenant JG John Hurst Chief Petty Officer Sean Maas APHIS OIC George Forcht Vessels Boarded NV19)Cedynia-Bulker NV20)Ipanema-Bulker NV21)Baltic Star-Reefer
5/1/92	Miami	USCG/MSO Chief Chason Keith Richter Bosuns Mate 1 Luis Santiago APHIS Inspector Carlos Riviera Mr. Boston Vessels Boarded NV22)Seaboard Horizon-RoRo NV23)Mercandian Ocean-RoRo

		NV24)Sunward-Cruise NV25)Nordic Empress-Cruise NV26)Christopher-Bulker
5/11-12/92	New Orleans (Baton Rouge)	USCG/MSO Chief Art Seddon Petty Officer Paul Ward Petty Officer Graves Johnson APHIS Bill Spitzer Vessels Boarded NV27)Hellspont Spirit-Tanker NV28)Congo River-Tanker NV29)Alchimist Lausanne-Tanker NV30)Knock Davie-Tanker NV31)Maritime Prosperity-Bulker NV32)Polska Walczaca-Bulker NV33)Chios Faith-Bulker NV34)Saramacca-General Cargo NV35)Sam Houston-LASH
5/14/92	Galveston (Freeport, Texas City)	USCG/MSO Lieutenant Ben Freeze Chief Wilson Ensign Randy Eagner Petty Officer Mike Muratorri APHIS Inspector Eddie Pitlyk Vessels Boarded NV36)Paci-General Cargo(Break Bulk) NV37)Qboys-General Cargo NV38)Stolt Excellence-Chemical Tanker NV39)Castillo De Monterrey-Bulker NV40)Tillie Lykes-Container
5/15/92	Houston	USCG/MSO Lieutenant Shelley Clapper Petty Officer Frederick Thornton APHIS Officer in Charge Carl Hatchett Vessels Boarded NV41)Sangstad-Chemical Tanker NV42)Orlik-General Cargo NV43)Turpial-Chemical Tanker NV44)Georgios P-Bulker NV45)Asian Banner-Bulker
6/1/92	Boston	USCG/MSO Chief Dan Barlett Hugh Smith

		Lieutenant Chris Oelschlegel APHIS Inspector Paige Awai Vessels Boarded NV46)Fuji Angel-Bulker NV47)Hofsjokull-Reefer NV48)Irving Eskimo-Tanker
6/8-10/92	Los Angeles Long Beach	USCG/MSO Senior Chief Condra Lieutenant Commander R. C. Lockwood Lieutenant T. R. Shields Petty Officer C. Phelps Petty Officer J. Luzader Petty Officer O D. Warden APHIS Officer in Charge Susan Spinella Supervisor V. Johnson Vessels Boarded NV49)Southward-Cruise NV50)Viking Serenade-Cruise NV51)Choyang Moscow-Container NV52)OOCL Fidelity-Container NV53)Blue Sky-Reefer NV54)Ocean Gold-Bulker NV55)Tonegawa-Chemical Tanker NV56)Star Rhode Island-Tanker NV57)Aniara-Car Carrier NV58)Gracious-Bulker NV59)Tundra Queen-Reefer NV60)Explorer-Bulker NV61)Ever Gleeful-Container NV62)Tampere-RoRo NV63)Century Leader #3-Car Carrier
6/12/92	San Diego	USCG/MSO Lieutenant JG J. Fritz Petty Officer R. Draney Port of San Diego Director Marine Operations S. Westover Assistant Director of Planning J. Wehbring APHIS Officer in Charge L. Redmond R. Tolles Vessels Boarded NV64)Thorseggen-Bulker
6/22-23/92	Honolulu	USCG/MSO Lieutenant B.L. DeShayes Petty Officer R. Minnich

		Petty Officer K. Smythe APHIS Mr. Tamiya Supervisor Daida Vessels Boarded NV65)Royal Accord-Container NV66)SeaLand Trader-Container NV67)Kauai-Container NV68)Columbus Victoria-Container NV69)Sierra Madre-Tanker NV70)Swiftnes-Bulker
6/24-25/92	San Francisco Oakland	USCG/MSO Lieutenant Lorne Thomas Petty Officer R. Leftridge APHIS Supervisor N. Mendel Mr. D. Wimmer Vessels Boarded NV71)SeaLand Endurance-Container NV72)Direct Kea-Container NV73)President Lincoln-Container NV74)Moana Pacific-Container/General Cargo NV75)Ever Gifted-Container NV76)Mayview Maersk-Container
7/13/92	Portland	USCG/MSO Petty Officer Clingenpeel Petty Officer S. Hooker APHIS Officer in Charge G. Smith Vessels Boarded NV77)Donaire-Car Carrier NV78)Grand Unity-Bulker NV79)Liberty Sun- Bulker NV80)Sanko Heritage-Bulker
7/15-17/92	Seattle Tacoma	USCG/MSO Chief Blume Petty Officer M. Shockley Lieutenant T L. Radziwanowicz APHIS W. Fontenelle Vessels Boarded NV81)Green Saikai-Bulker (Log) NV82)Shintonami-Bulker (Wood chips) NV83)Pan Zenith- Bulker NV84)Hanjin Soeul-Container NV85)Celtic Light-Bulker NV86)Columbus Virginia-Container

NV87)Emma Oldendorff-Container
NV88)Pacific Span-Container
NV89)Sealand Anchorage-Container
NV90)Tower Bridge-Container
NV91)Ever Linking-Container
NV92)Sealand Trader-Container
NV93)California Star-Container
NV94)Puhe-Container

7/21-22-92	Anchorage Kenai	USCG/MSO Lieutenant Wilson J. Quitniak Petty Officer Sazer APHIS Officer in Charge F. Rothgery Port of Anchorage Mr. J. Brown (Operations Manager) Vessels Boarded NV95)Westward Venture-RoRo NV96)Sealand Tacoma-Container NV97)Nomadic Breeze-Bulker

APPENDIX C

<u>Monthly Arrival/In Ballast Tables (1991) from TM385 (Vessel Entrances):</u>

Northeast Coast of the United States:

Boston, New York, Baltimore, Norfolk

Southeast Coast of the United States:

Charleston, Savannah, Miami

<u>Monthly Arrival/In Ballast Tables (1991) from TM385 (Vessel Entrances):</u>

Northwest Coast of the United States:

Portland, Tacoma, Seattle

Southwest Coast of the United States:

San Diego, Long Beach, Los Angeles, Oakland, San Francisco

<u>Monthly Arrival/In Ballast Tables (1991) from TM385 (Vessel Entrances):</u>

Gulf Coast of the United States:

Tampa, New Orleans, Houston, Galveston

Alaska and Hawaiian Islands:

Anchorage, Honolulu

Where,

ARR = Number of vessel arrivals

BAL = Number of vessels arriving in ballast

Monthly Arrivals in Ballast (1991)
(from Census TM385/Vessel Entrances)

North East Coast of the United States.

Port	Boston		New York		Baltimore		Norfolk	
DPC	0401		1001		1303		1401	
Month	ARR	BAL	ARR	Bal	ARR	Bal	ARR	Bal
Jan	59	2	315	11	164	11	190	31
Feb	44	2	277	12	142	14	192	35
March	58	3	298	3	150	14	191	47
April	61	1	344	11	181	14	181	35
May	61	2	368	20	167	9	220	50
June	49	3	346	30	164	15	191	40
July	46	1	362	25	176	20	195	28
Aug	50	5	376	31	175	22	205	39
Sept	61	5	370	25	175	22	210	43
Oct	63	7	344	18	185	20	188	21
Nov	56	4	337	9	185	28	190	28
Dec	58	1	321	10	179	15	194	28
Total	666	36	4058	205	2043	204	2347	425

South East Coast of the United States.

Port	Charleston		Savannah		Miami	
DPC	1601		1703		5201	
Month	ARR	Bal	ARR	Bal	ARR	Bal
Jan	122	5	140	4	431	173
Feb	109	2	136	9	400	164
March	115	7	131	8	535	259
April	121	4	149	7	568	248
May	124	5	158	11	504	235
June	107	3	147	8	522	273
July	126	6	153	9	513	232
Aug	124	4	154	10	539	253
Sept	133	4	143	11	484	218
Oct	130	6	157	10	492	186
Nov	105	3	151	5	488	205
Dec	117	1	138	5	508	219
Total	1433	50	1757	97	5984	2665

Monthly Arrivals in Ballast (1991)
(from Census TM385/Vessel Entrances)

North West Coast of the United States.

Port	Portland		Tacoma		Seattle	
DPC	2904		3002		3001	
Month	ARR	Bal	ARR	Bal	ARR	Bal
Jan	78	19	141	26	212	10
Feb	72	20	118	28	189	15
March	82	21	166	33	210	6
April	70	19	127	22	204	11
May	79	21	146	21	238	16
June	78	17	129	19	224	13
July	82	17	138	28	231	21
Aug	97	22	154	35	238	23
Sept	90	23	118	26	248	21
Oct	83	22	132	28	264	29
Nov	81	29	131	28	205	19
Dec	93	25	110	22	209	29
Total	985	255	1610	316	2672	213

South West Coast of the United States.

Port	San Diego		Long Beach		Los Angeles		Oakland		San Francisco	
DPC	2501		2709		2704		2811		2809	
Month	ARR	Bal	ARR	Bal	ARR	Bal	ARR	Bal	ARR	Bal
Jan	87	60	215	19	239	60	107	2	68	1
Feb	110	83	188	17	237	46	98	4	53	4
March	130	95	200	13	217	40	100	1	58	1
April	117	77	190	9	233	53	100	0	63	1
May	102	48	215	16	237	60	113	1	67	2
June	75	36	229	25	205	34	105	0	61	7
July	63	40	231	25	204	32	107	0	63	6
Aug	61	39	192	16	195	33	112	1	57	6
Sept	61	39	196	21	191	37	107	1	66	11
Oct	76	40	199	17	207	34	123	1	64	4
Nov	77	45	166	17	199	48	103	1	57	1
Dec	79	48	187	25	207	57	108	2	57	0
Total	1038	650	2408	220	2571	534	1283	14	734	44

Monthly Arrivals in Ballast (1991)
(from Census TM385/Vessel Entrances)

Gulf Coast of the United States.

Port	Tampa		New Orleans		Houston		Galveston	
DPC	1801		2002		5301		5310	
Month	ARR	Bal	Arr	Bal	ARR	Bal	ARR	Bal
Jan	156	41	337	100	343	55	42	12
Feb	123	40	342	116	356	72	57	9
March	138	35	352	140	351	62	48	17
April	118	34	288	85	360	50	101	49
May	136	35	314	89	374	53	83	32
June	110	30	288	81	366	56	49	31
July	110	29	355	137	361	54	43	12
Aug	106	25	333	112	354	58	71	44
Sept	112	28	277	73	342	58	74	42
Oct	113	29	333	107	349	59	73	32
Nov	128	37	314	90	321	51	40	5
Dec	126	33	366	132	349	68	53	8
Total	1476	396	3899	1262	4226	696	734	293

Alaska & Hawaiian Islands.

Port	Anchorage		Honolulu	
DPC	3126		3201	
Month	ARR	Bal	ARR	Bal
Jan	73	32	107	31
Feb	82	15	109	44
March	106	31	122	30
April	91	36	100	25
May	115	25	106	31
June	135	38	121	35
July	167	34	105	29
Aug	136	25	82	21
Sept	77	15	87	20
Oct	45	17	100	28
Nov	46	17	100	22
Dec	50	18	88	31
Total	1123	303	1227	347

APPENDIX D

ACKNOWLEDGED BALLAST (METRIC TONS) IN TANKERS, BULKERS, AND GENERAL CARGO VESSELS (CI = Confidence Intervals)

TM385 Census Data: Acknowledged Ballast: Tankers
TM385 Census Data: Acknowledged Ballast: Bulkers
TM385 Census Data: Acknowledged Ballast: General Cargo Vessels

Acknowledged ballast: Tankers: East Coast
Acknowledged ballast: Tankers: Gulf Coast
Acknowledged ballast: Tankers: West Coast
Acknowledged ballast: Tankers: Alaska and Hawaii

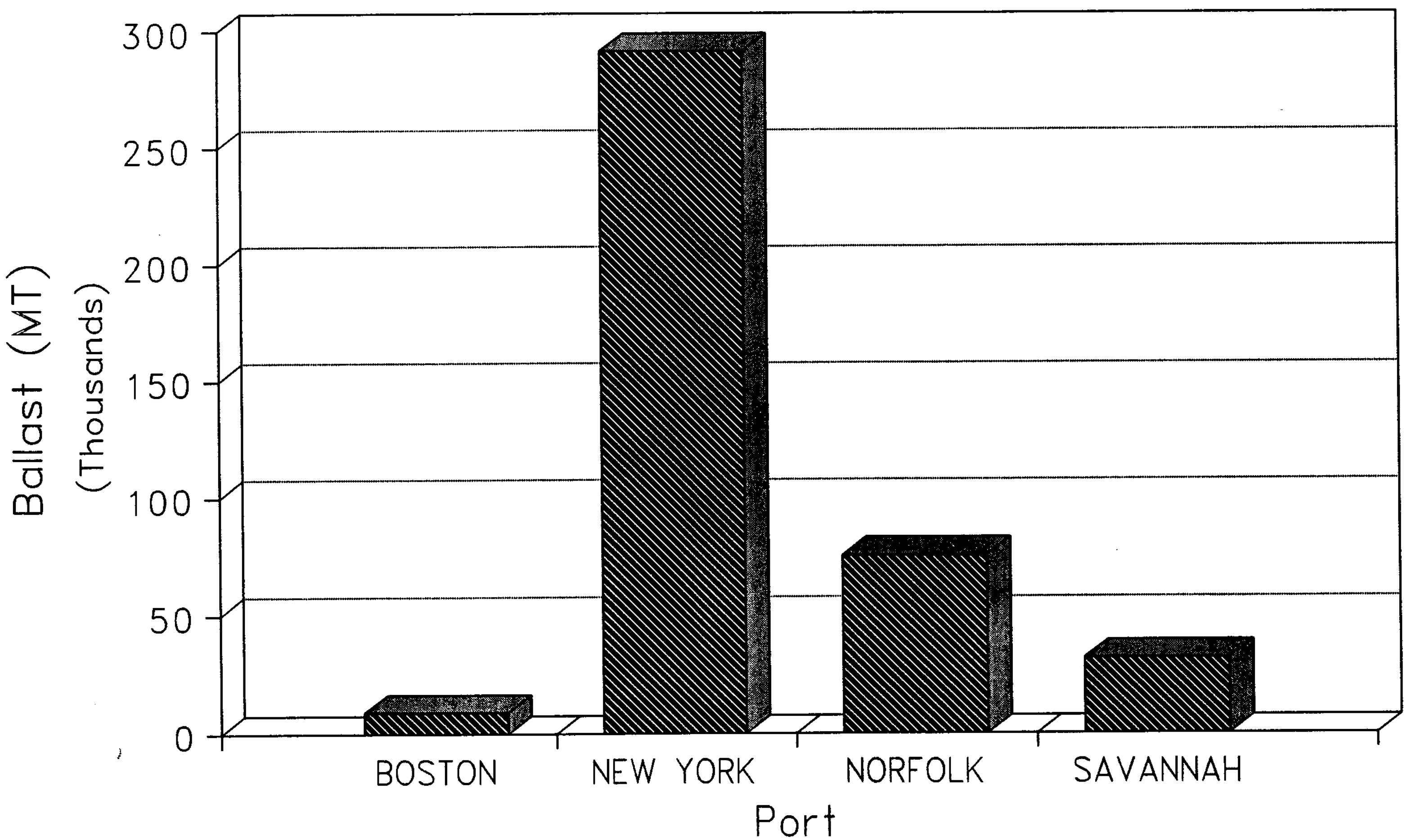
Acknowledged ballast: Bulkers: East Coast
Acknowledged ballast: Bulkers: Gulf Coast
Acknowledged ballast: Bulkers: West Coast
Acknowledged ballast: Bulkers: Alaska and Hawaii

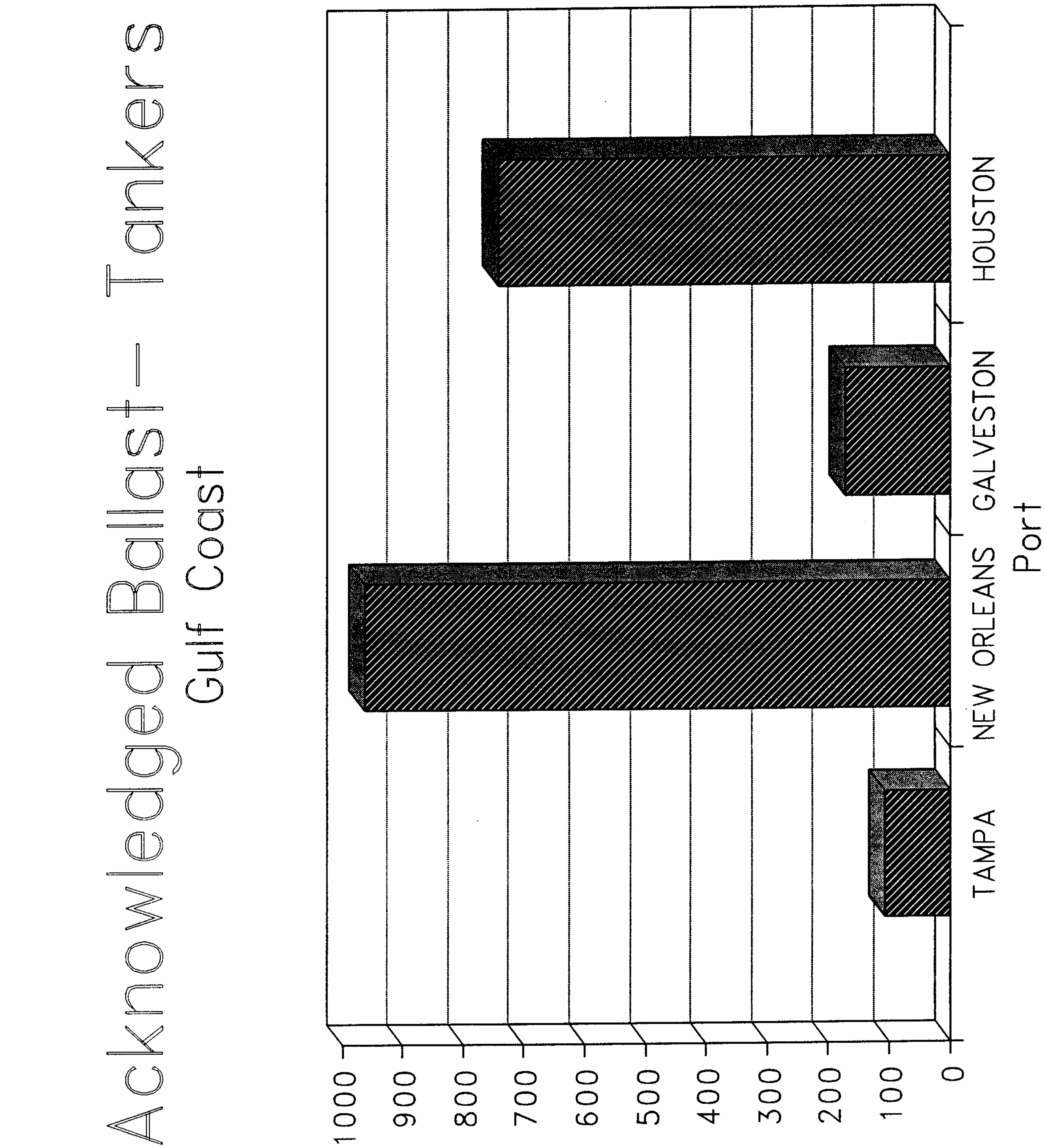
Acknowledged ballast: General Cargo: East Coast
Acknowledged ballast: General Cargo: Gulf Coast
Acknowledged ballast: General Cargo: West Coast and Hawaii

TM385 Census Data: Acknowledged Ballast: TANKERS

PORT	VESSELS IN BALLAST	MEAN BAL CAP	95 % CI	TOTAL BAL CAP	ESTIMATED BAL ARRIVAL
BOSTON	1	11132	8430	11132	8533
NEW YORK	27	14087	9807	380349	291538
NORFOLK	7	14059	9795	98413	75434
SAVANNAH	3	13983	9761	41949	32154
TAMPA	33	4217	4084	139161	106667
NEW ORLEANS	63	19952	12219	1256976	963472
GALVESTON	34	6655	5856	226270	173436
HOUSTON	128	7573	6436	969344	743002
LONG BEACH	66	59878	23603	3951948	3029168
LOS ANGELES	27	11092	8383	299484	229554
SAN FRANCISCO	4	11720	8695	46880	35934
PORTLAND	4	66306	25069	265224	203294
SEATTLE	7	19388	12005	135716	104026
ANCHORAGE	25	15954	10620	398850	305719
HONOLULU	17	5163	4821	87771	67276
TOTAL	446			8309467	6369206

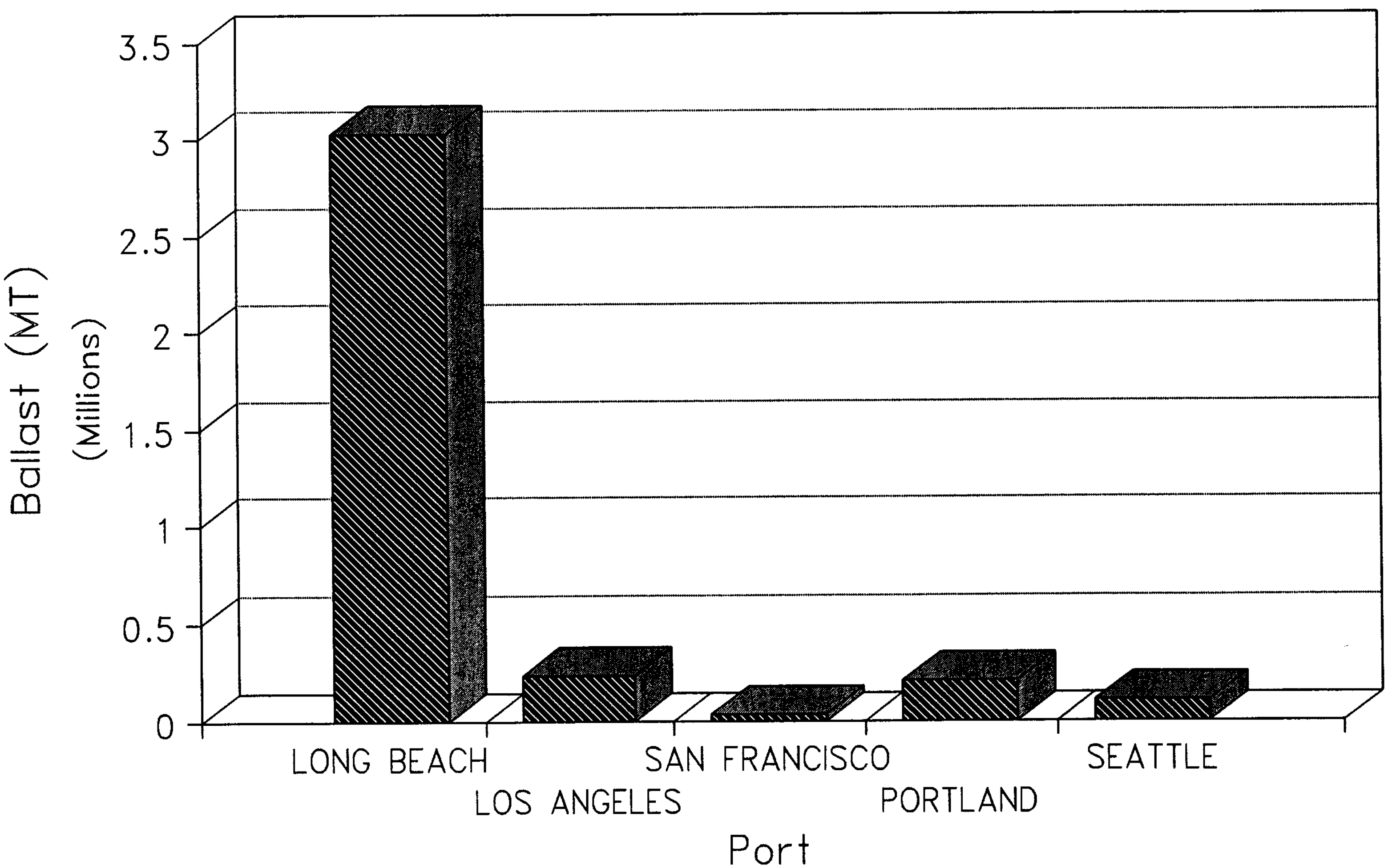
Acknowledged Ballast– Tankers
East Coast

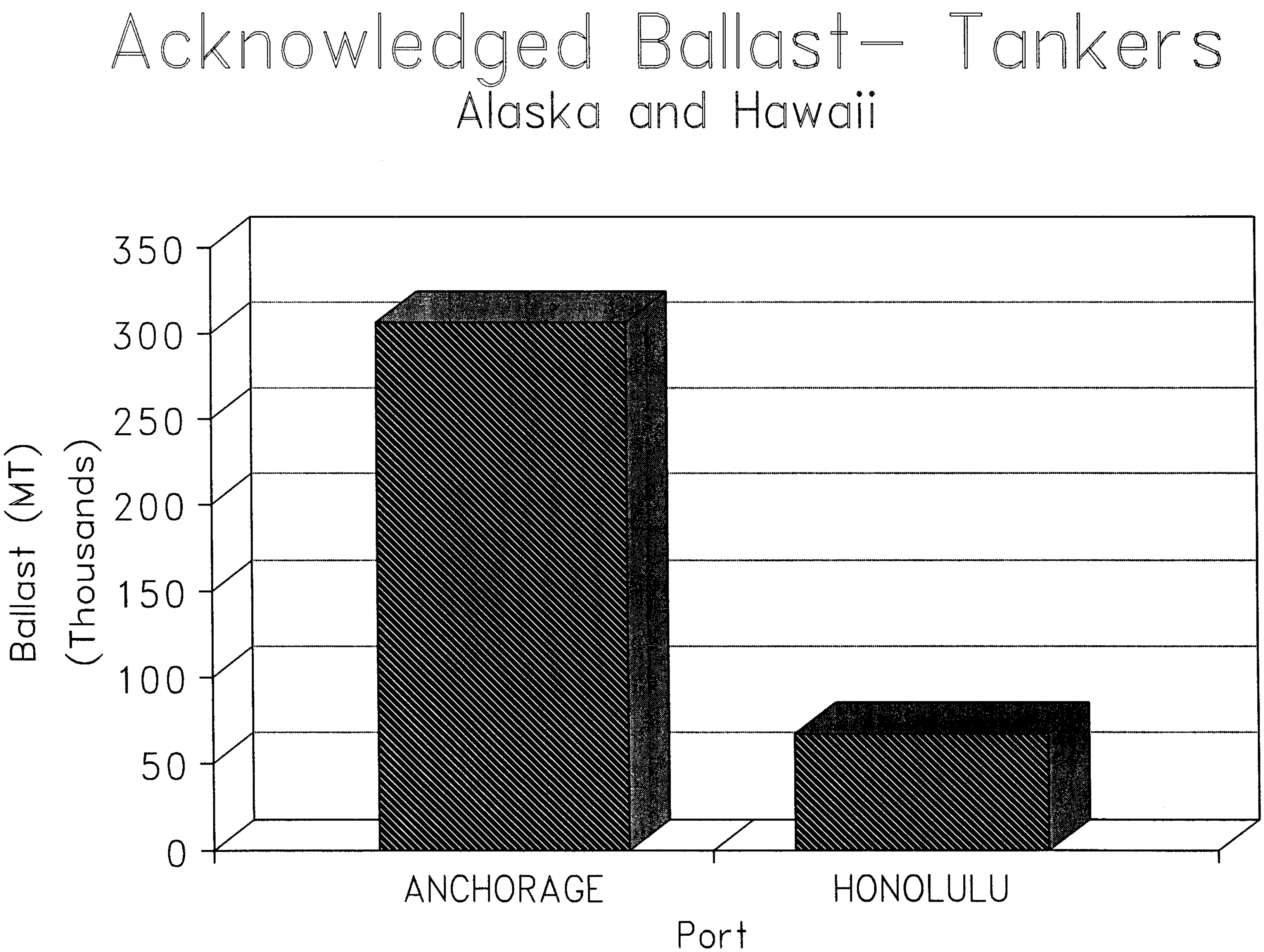



Acknowledged Ballast — Tankers
Gulf Coast
Ballast (MT)
(Thousands)
1000
900
800
700
600
500
400
300
200
100
0
TAMPA
NEW ORLEANS
GALVESTON
HOUSTON
Port

Acknowledged Ballast– Tankers

West Coast

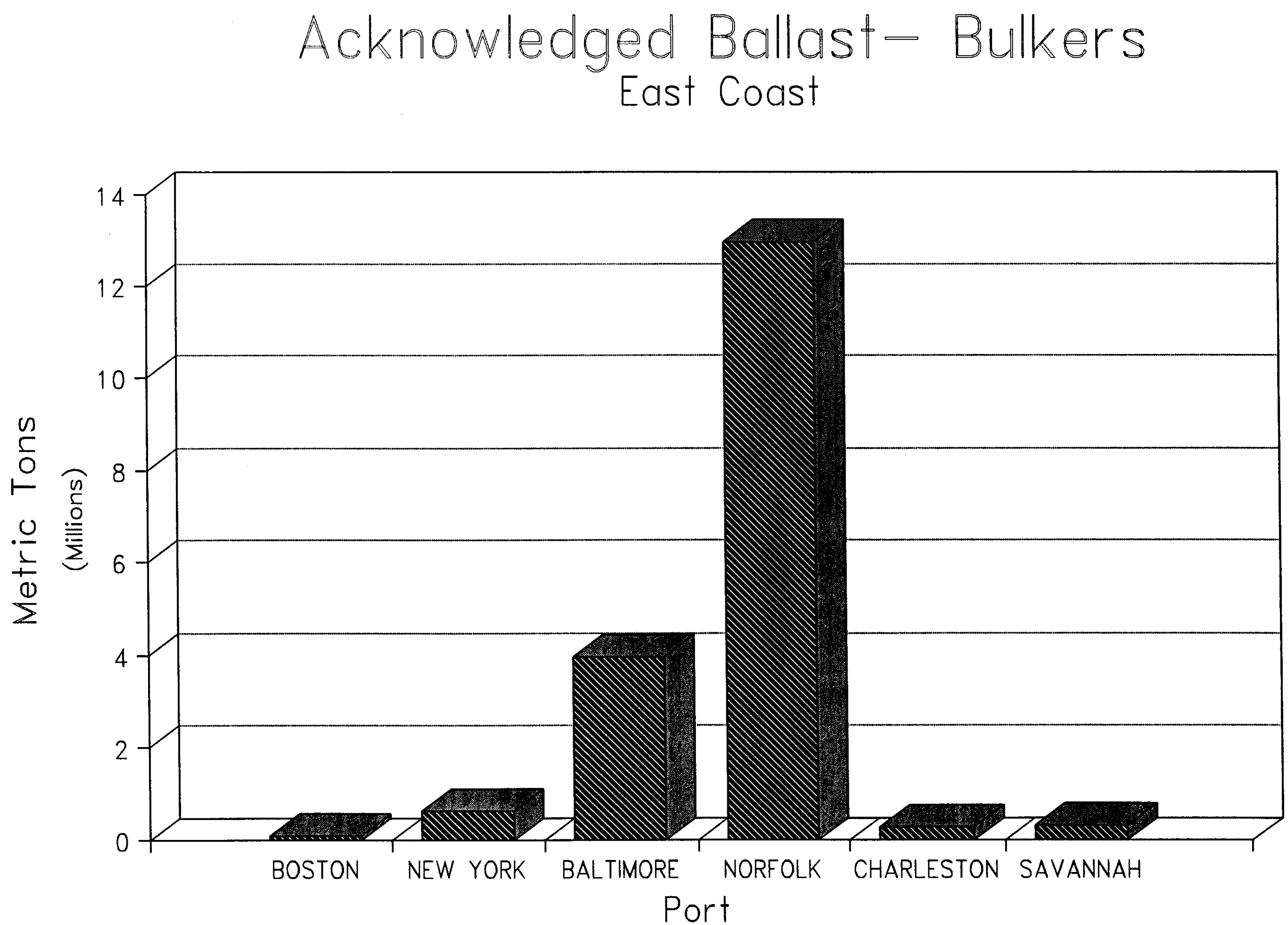




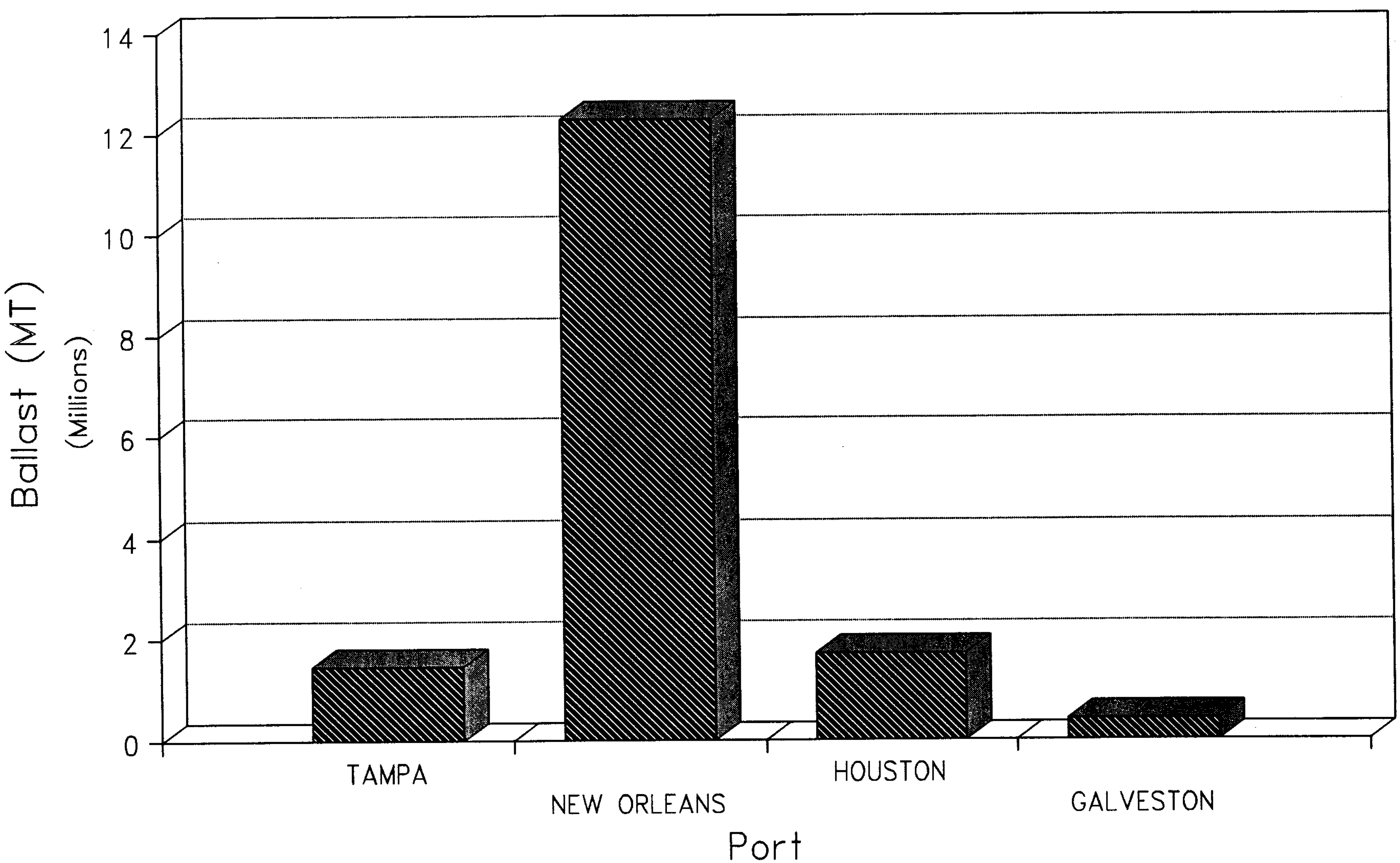
Acknowledged Ballast– Tankers
Alaska and Hawaii
Ballast (MT)
(Thousands)
350
300
250
200
150
100
50
0
ANCHORAGE
HONOLULU
Port

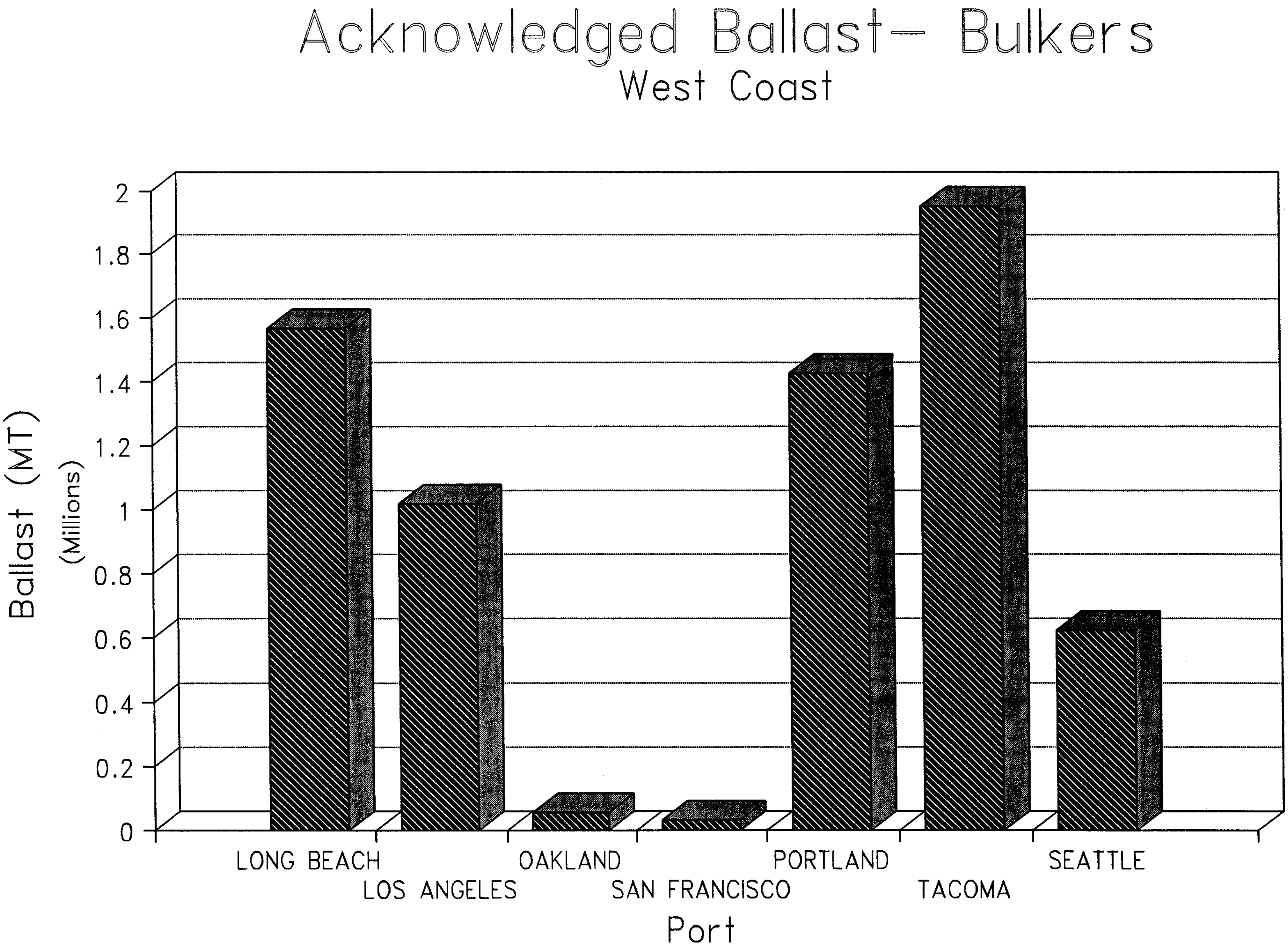
TM385 Census Data: Acknowledged Ballast: BULKERS

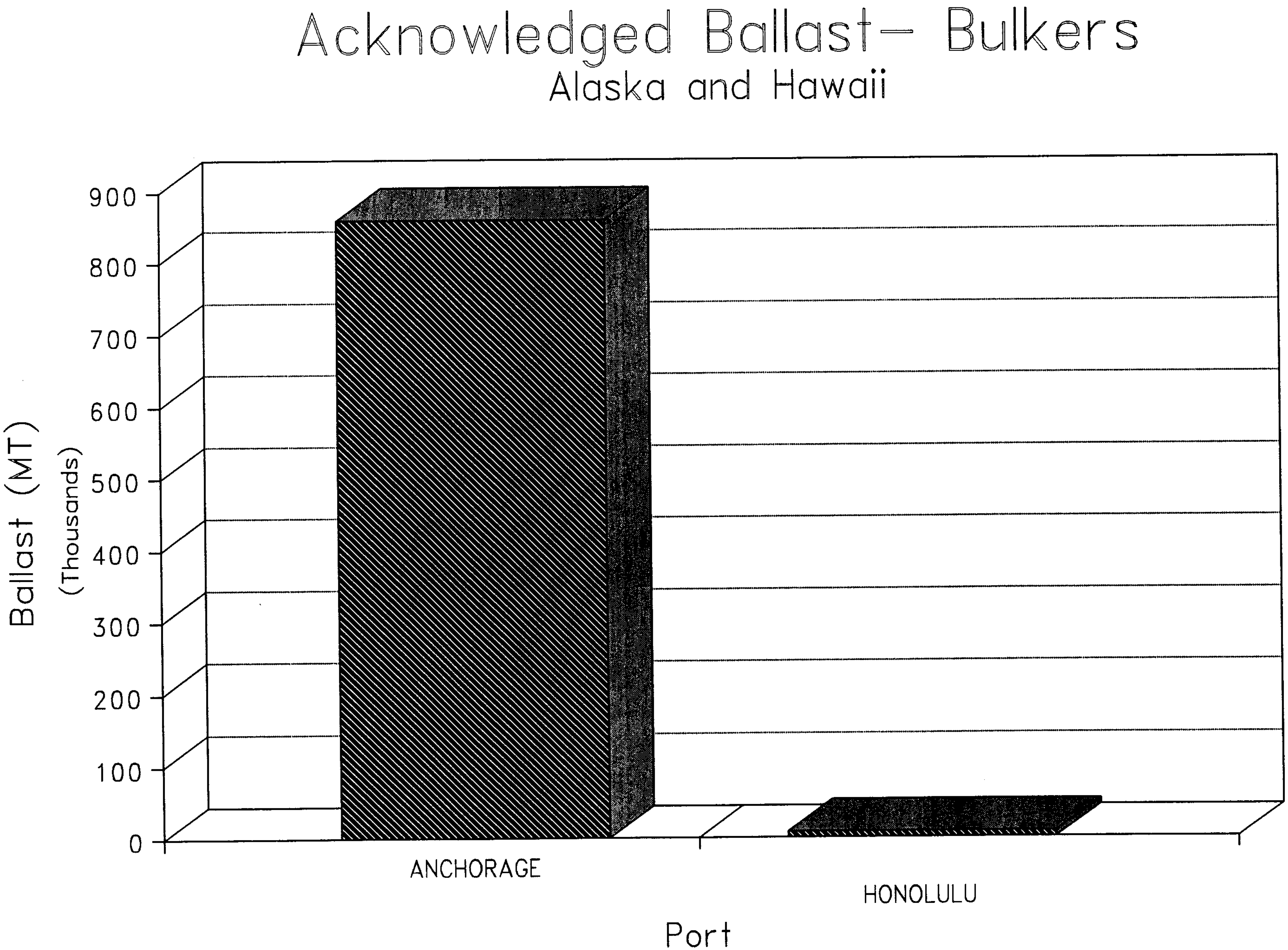
PORT	VESSELS IN BALLAST	MEAN BAL CAP	95 % CI	TOTAL BAL CAP	ESTIMATED BAL ARRIVAL
BOSTON	5	18247	9840	91235	65014
NEW YORK	44	13813	8315	613297	437036
BALTIMORE	190	20883	10660	3961505	2822969
NORFOLK	390	33237	13960	12949135	9227554
CHARLESTON	22	13078	8041	287716	205026
SAVANNAH	19	16221	9168	314687	224246
TAMPA	184	11099	7260	2041106	1454492
NEW ORLEANS	882	19538	10247	17232516	12279891
HOUSTON	174	13694	8272	2382756	1697952
GALVESTON	49	11253	7323	549484	391562
LONG BEACH	117	18742	9998	2198437	1566606
LOS ANGELES	84	17085	9460	1432236	1020611
OAKLAND	8	9412	6538	75296	53656
SAN FRANCISCO	5	8058	5910	40290	28711
PORTLAND	200	10038	6813	2003585	1427755
TACOMA	195	14049	8403	2736745	1950205
SEATTLE	43	20426	10520	874233	622978
ANCHORAGE	76	15868	9047	1205968	859373
HONOLULU	1	9208	6447	9208	6562
TOTAL	2687			50999435	36342197


Acknowledged Ballast- Bulkers
East Coast
Metric Tons
(Millions)
14
12
10
8
6
4
2
0
BOSTON
NEW YORK
BALTIMORE
NORFOLK
CHARLESTON
SAVANNAH
Port

Acknowledged Ballast– Bulkers
Gulf Coast



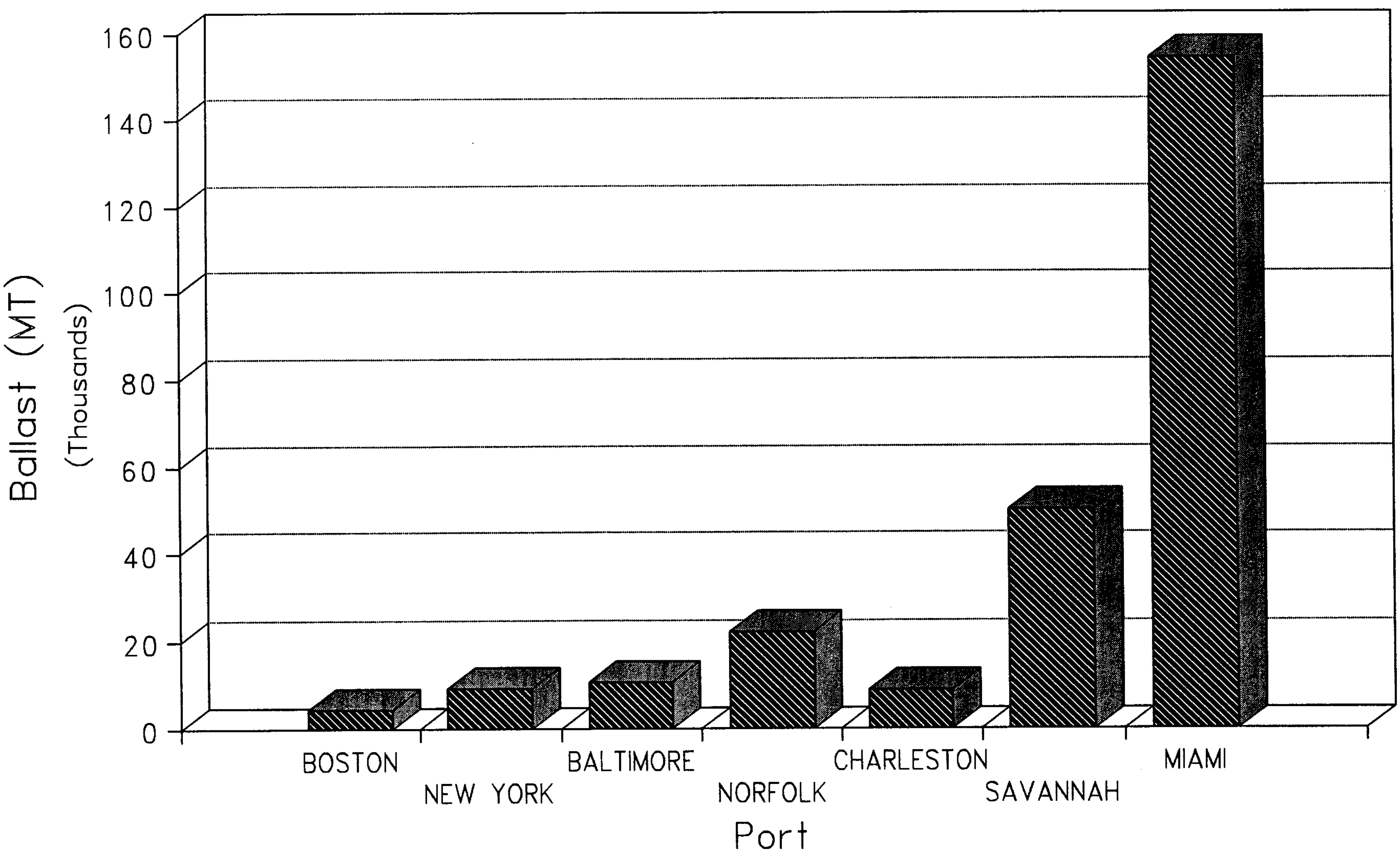

Acknowledged Ballast– Bulkers
West Coast
Ballast (MT)
(Millions)
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
LONG BEACH
LOS ANGELES
OAKLAND
SAN FRANCISCO
PORTLAND
TACOMA
SEATTLE
Port


Acknowledged Ballast– Bulkers
Alaska and Hawaii
Ballast (MT)
(Thousands)
900
800
700
600
500
400
300
200
100
0
ANCHORAGE
HONOLULU
Port

TM385 Census Data: Acknowledged Ballast: GENERAL CARGO VESSELS

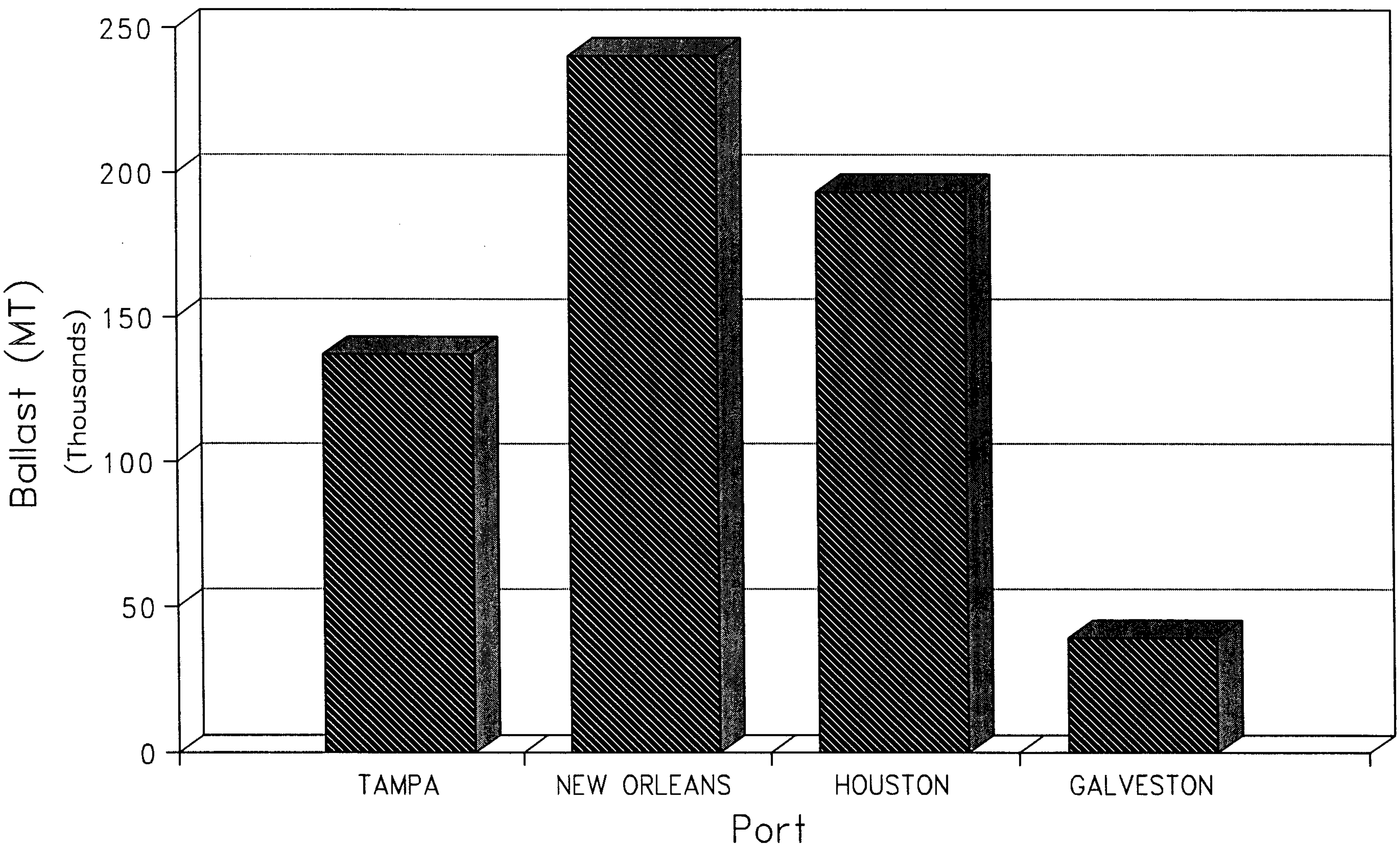
PORT	VESSELS IN BALLAST	MEAN BAL CAP	95 % CI	TOTAL BAL CAP	ESTIMATED BAL ARRIVAL
BOSTON	2	3067	2297	6134	4351
NEW YORK	7	1816	1591	12712	9018
BALTIMORE	3	5056	3179	15168	10760
NORFOLK	7	4462	2935	31234	22157
CHARLESTON	7	1736	1539	12152	8621
SAVANNAH	44	1610	1454	70840	50254
MIAMI	266	817	817	217322	154168
TAMPA	99	1955	1679	193545	137301
NEW ORLEANS	168	2017	1718	338856	240384
HOUSTON	209	1303	1232	272327	193189
GALVESTON	20	2802	2161	56040	39755
LOS ANGELES	18	2497	1997	44946	31885
OAKLAND	4	3607	2557	14428	10235
SAN FRANCISCO	1	4216	2830	4216	2991
PORTLAND	8	4855	3098	38840	27553
SEATTLE	4	3809	2650	15236	10808
HONOLULU	6	1173	1130	7038	4993
TOTAL	873			1351034	958424

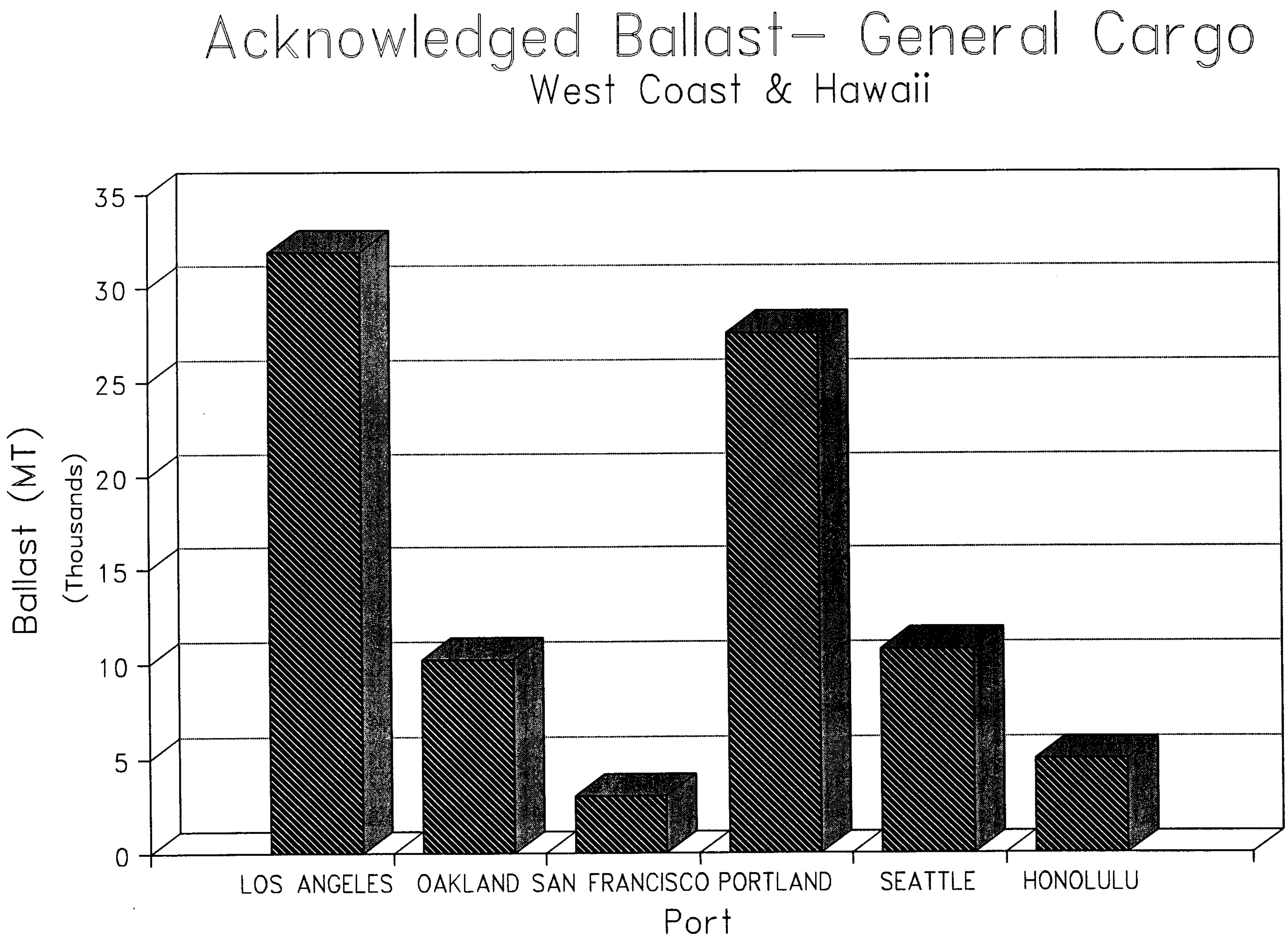
Acknowledged Ballast– General Cargo
East Coast



Acknowledged Ballast– General Cargo

Gulf Coast





Acknowledged Ballast– General Cargo
West Coast & Hawaii
Ballast (MT)
(Thousands)
35
30
25
20
15
10
5
0
LOS ANGELES
OAKLAND
SAN FRANCISCO
PORTLAND
SEATTLE
HONOLULU
Port

APPENDIX E

UNACKNOWLEDGED BALLAST (METRIC TONS)

(CI = Confidence Intervals)

(1) UNACKNOWLEDGED BALLAST for bulkers, containers, and tankers from foreign ports arriving in cargo in five selected ports of the US East, Gulf, and West Coasts: Baltimore, Norfolk, Oakland, San Francisco, New Orleans

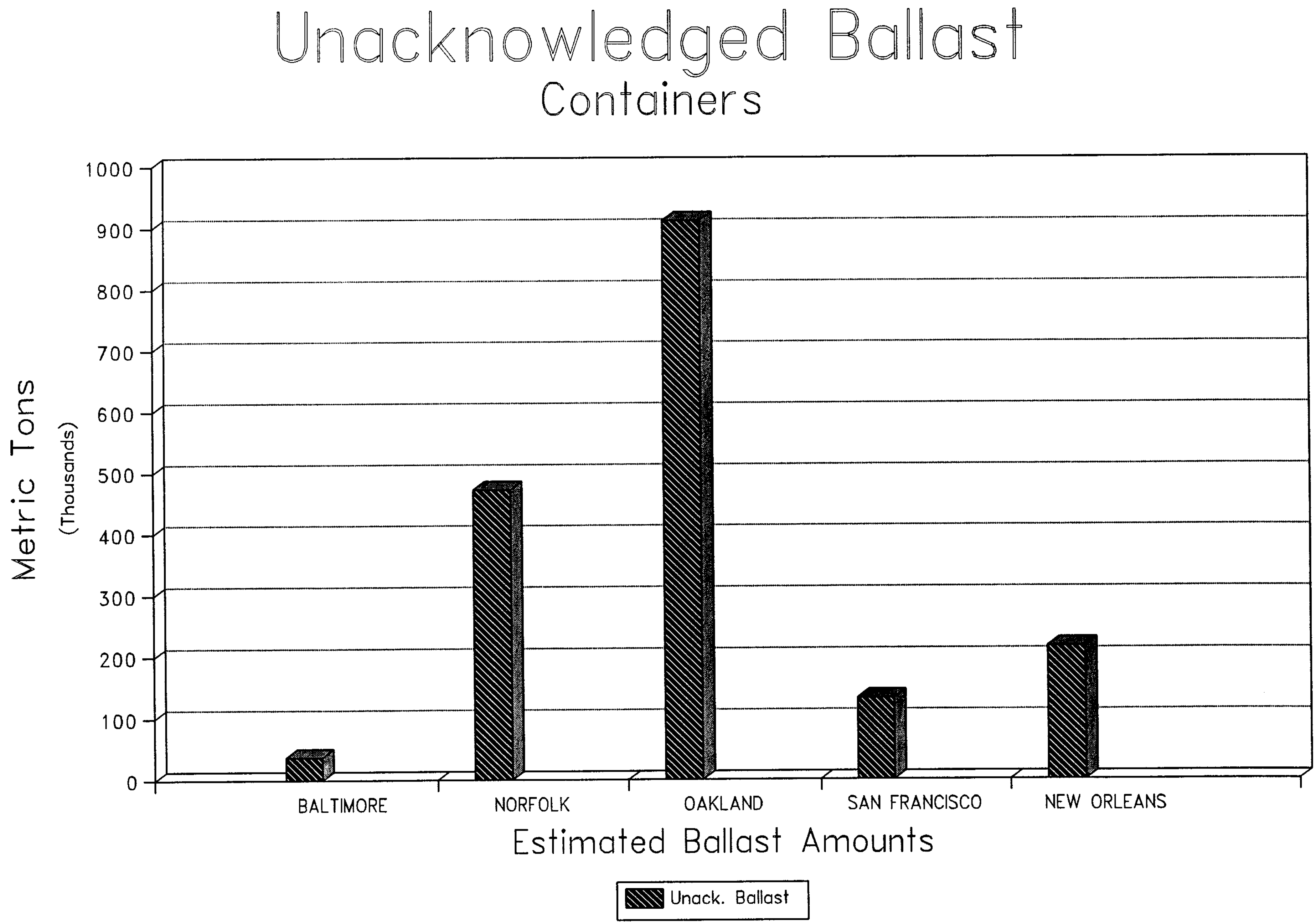
(2) Unacknowledged ballast: Containers: Five ports compared

(3) Unacknowledged ballast: Containers: Baltimore and Norfolk

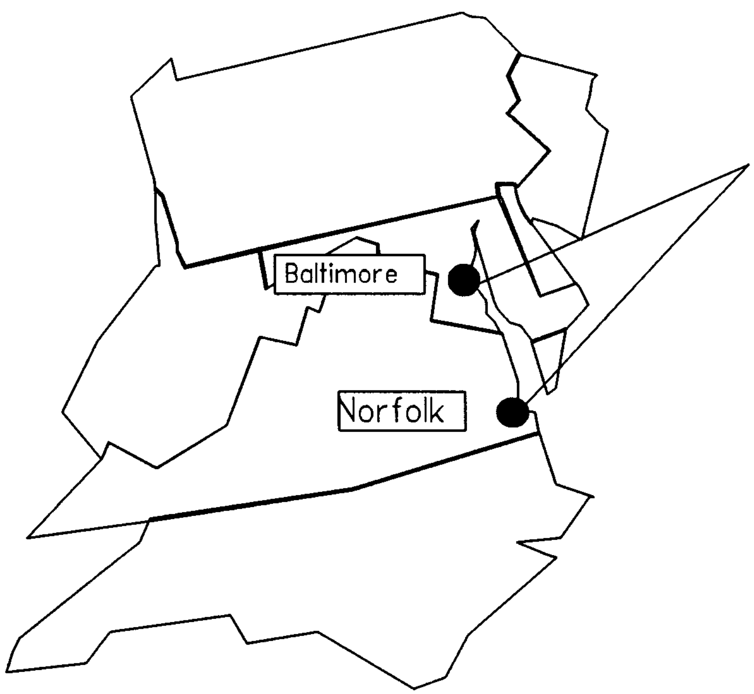
(4) Unacknowledged ballast: Containers: San Francisco and Oakland

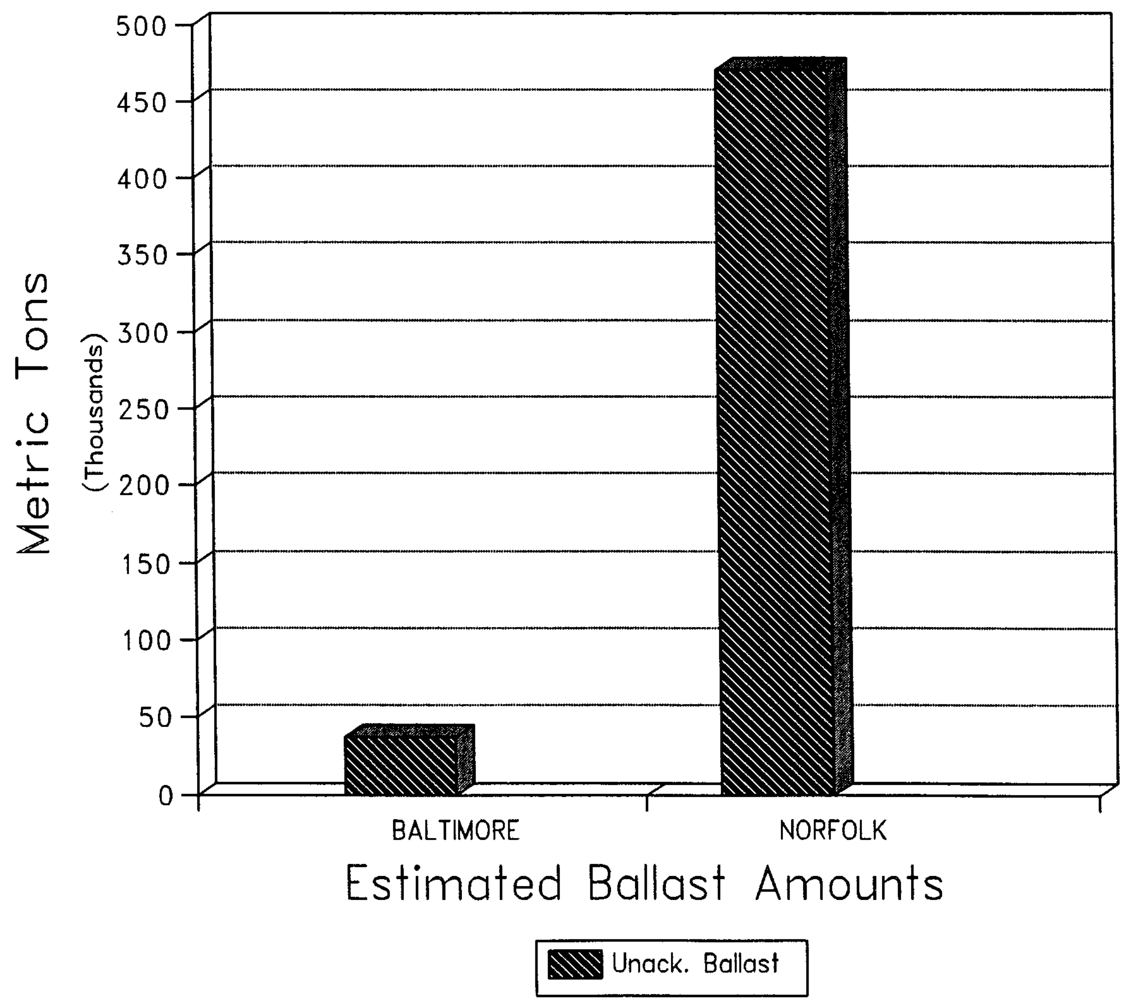
Unacknowledged Ballast (MT) for Bulkers, Containers, and Tankers from Foreign Ports Arriving in Cargo in Five Selected Ports of the US East, Gulf, and West Coasts

	% FOREIGN IN CARGO	EST. ARR	AVG BALLAST	95% CI	AVG UNACK BALLAST
BALTIMORE					
BULKERS	9.03	184	6326.6	3900.7	1164094
CONTAINERS	0.35	7	5227.9	1021	36595
TANKERS	3.47	71	2420.3	1815.3	171841
TOTAL		262			1372531
NORFOLK					
BULKERS	6.25	147	6326.6	3900.7	930010
CONTAINERS	3.82	90	5227.9	1021	[illegible]70511
TANKERS	1.04	24	2420.3	1815.3	[illegible]3087
TOTAL		261			1458608
OAKLAND					
BULKERS	2.43	31	6326.6	3900.7	196125
CONTAINERS	13.54	174	5227.9	1021	909655
TANKERS	0	0	2420.3	1815.3	0
TOTAL		205			1105779
SAN FRANCISCO					
BULKERS	1.04	8	6326.6	3900.7	50613
CONTAINERS	3.47	25	5227.9	1021	130697
TANKERS	2.08	15	2420.3	1815.3	36305
TOTAL		48			217615
NEW ORLEANS					
BULKERS	5.56	217	6326.6	3900.7	1372872
CONTAINERS	1.04	41	5227.9	1021	214344
TANKERS	8.68	338	2420.3	1815.3	818061
TOTAL		596		TOTAL	2405278
TOTAL		1372			6559811

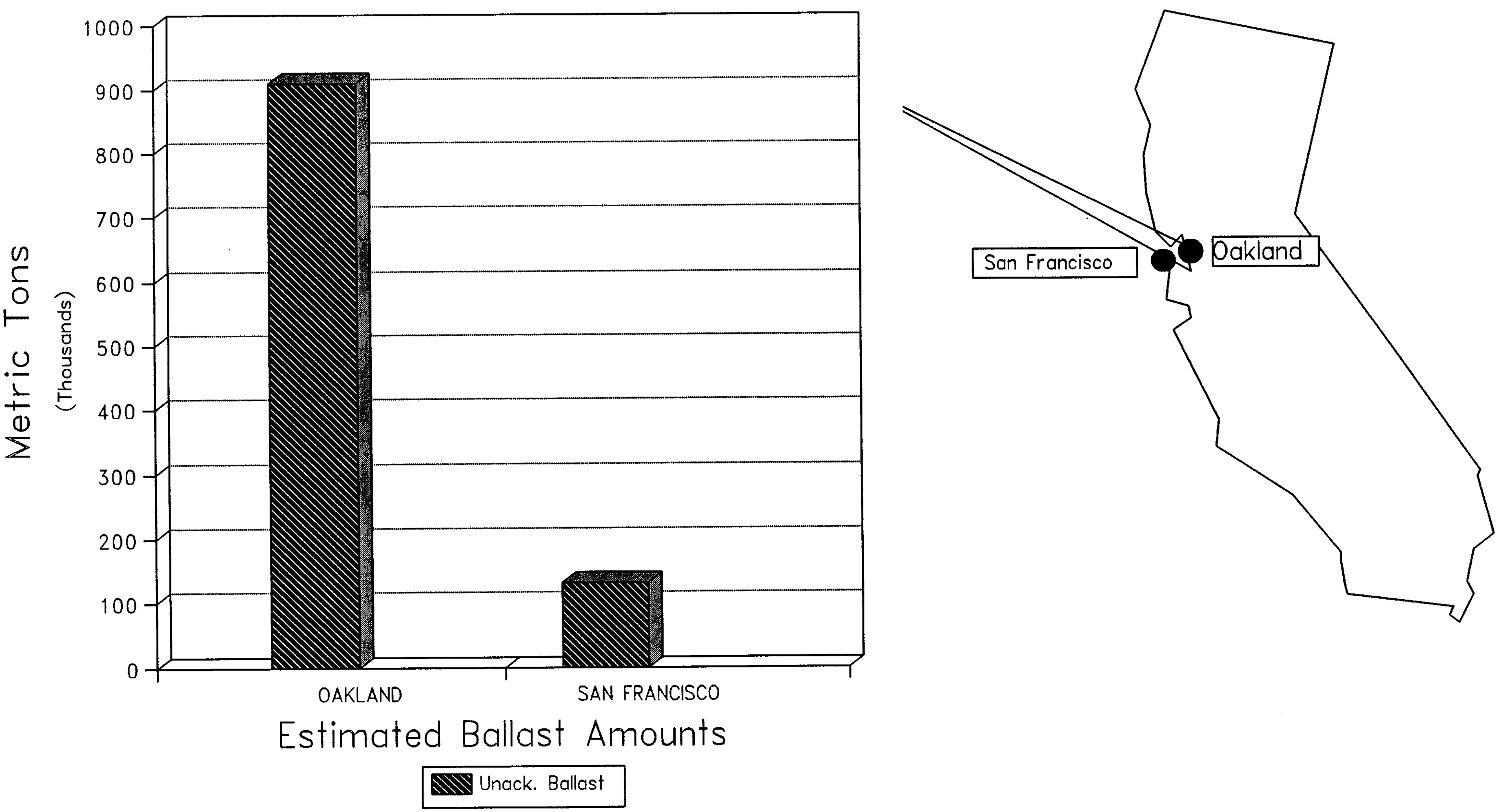

Unacknowledged Ballast
Containers
Metric Tons
(Thousands)
1000
900
800
700
600
500
400
300
200
100
0
BALTIMORE
NORFOLK
OAKLAND
SAN FRANCISCO
NEW ORLEANS
Estimated Ballast Amounts
Unack. Ballast

Unacknowledged Ballast
Containers





Unacknowledged Ballast Containers



APPENDIX F

UNACKNOWLEDGED VERSUS ACKNOWLEDGED BALLAST

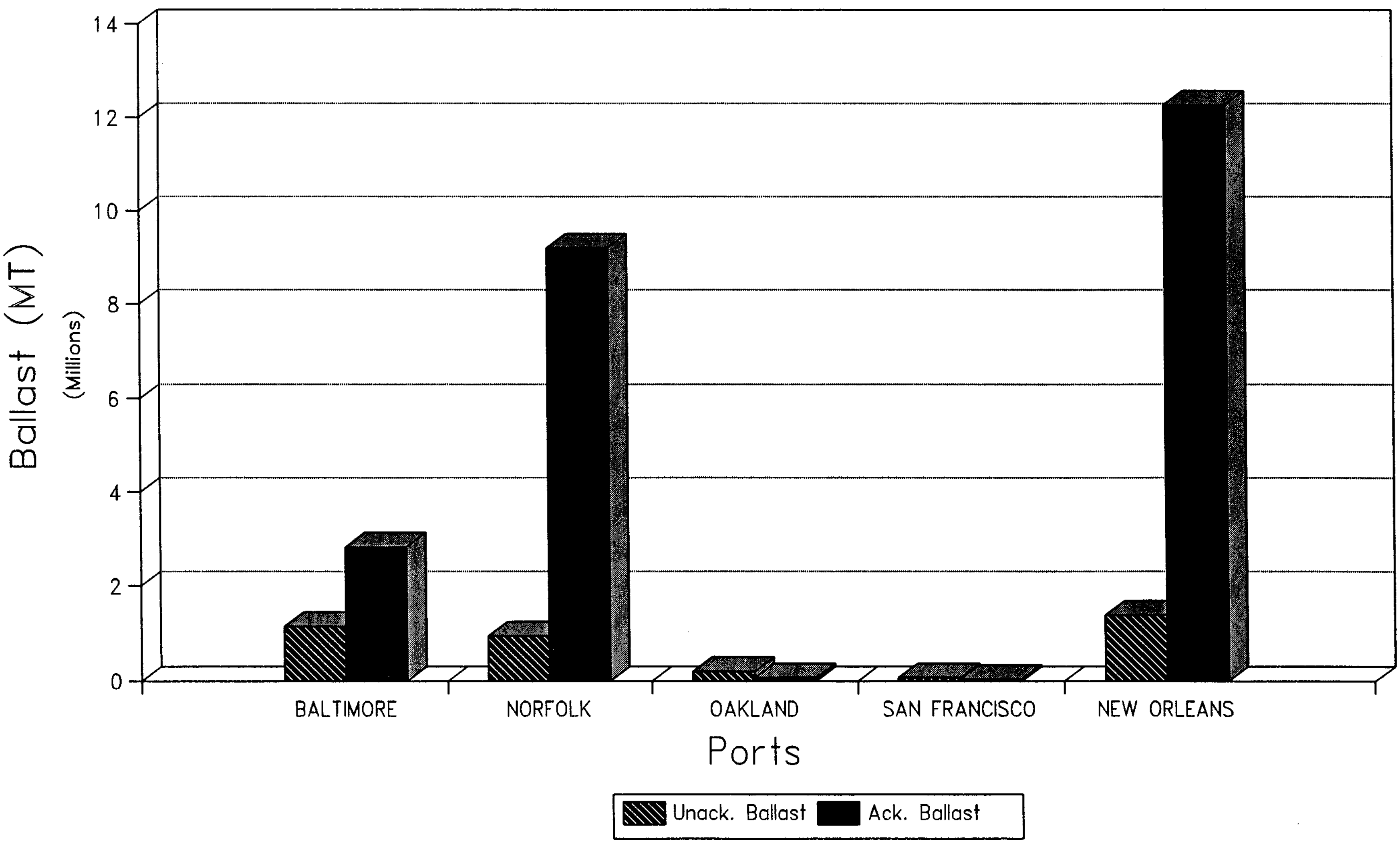
BULKERS

Unacknowledged vs. acknowledged ballast: Bulkers: Five ports compared
Unacknowledged vs. acknowledged ballast: Bulkers: Baltimore and Norfolk
Unacknowledged vs. acknowledged ballast: Bulkers: San Francisco and Oakland
Unacknowledged vs. acknowledged ballast: Bulkers: New Orleans

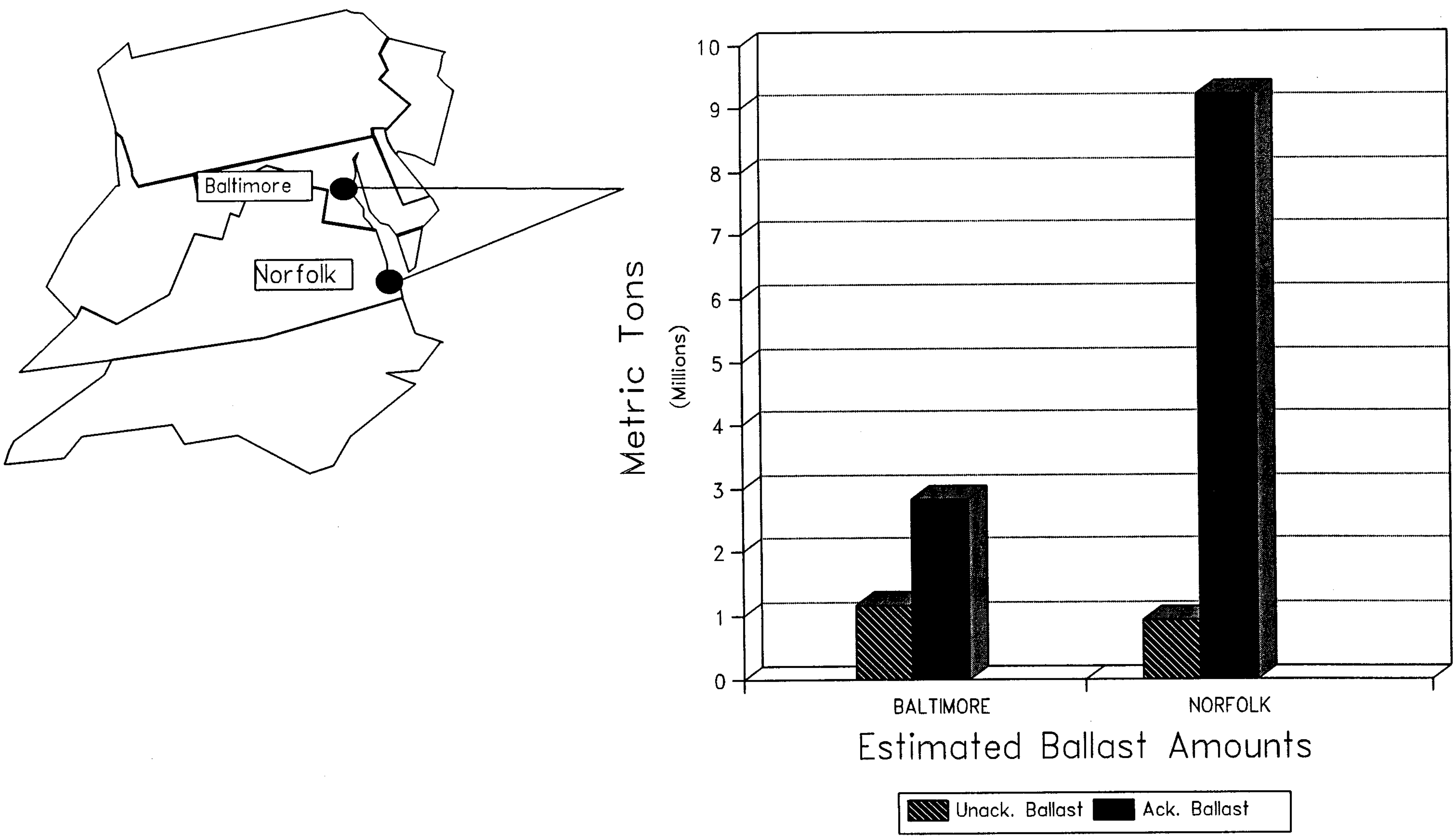
TANKERS

Unacknowledged vs. acknowledged ballast: Tankers: Five ports compared
Unacknowledged vs. acknowledged ballast: Tankers: Baltimore and Norfolk
Unacknowledged vs. acknowledged ballast: Tankers: San Francisco and Oakland
Unacknowledged vs. acknowledged ballast: Tankers: New Orleans

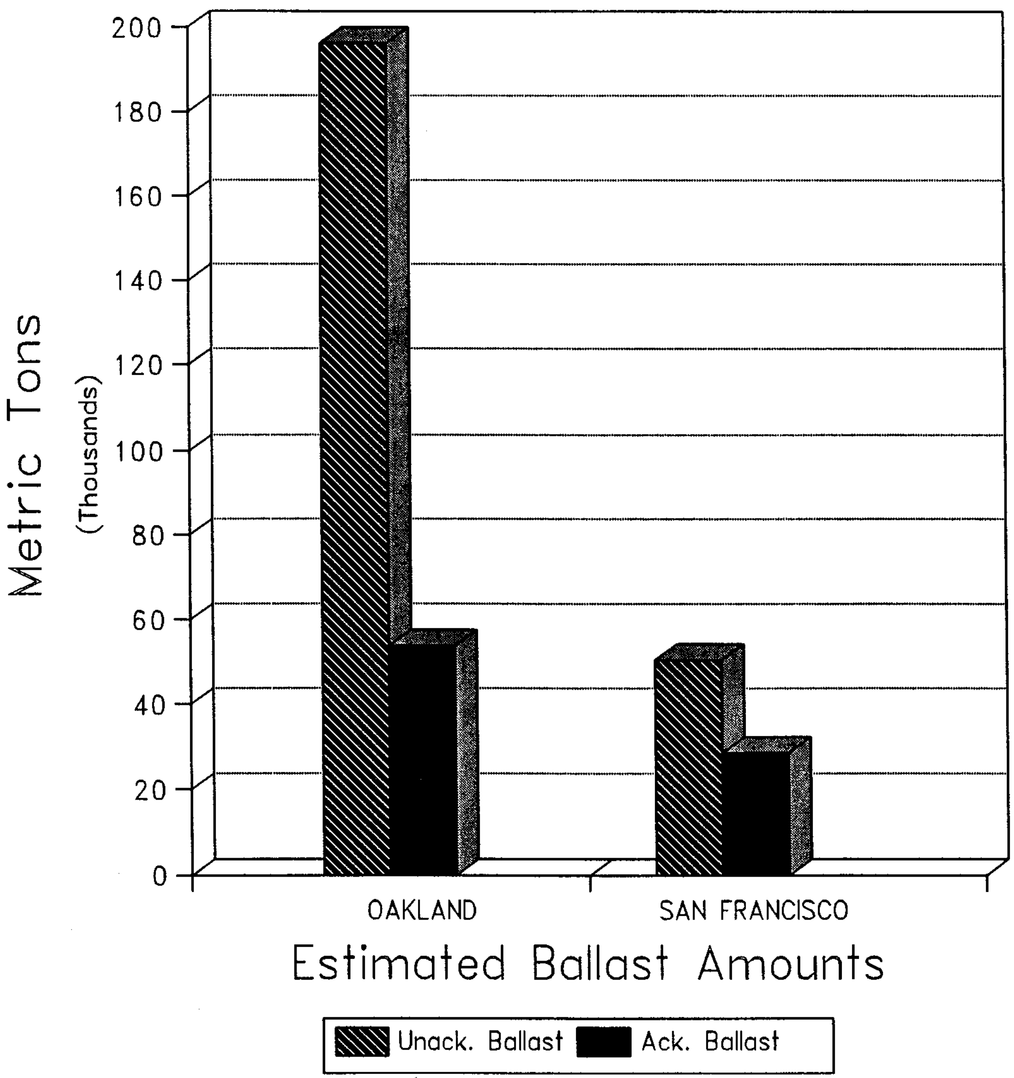
Unacknowledged vs. Acknowledged Ballast
Bulkers

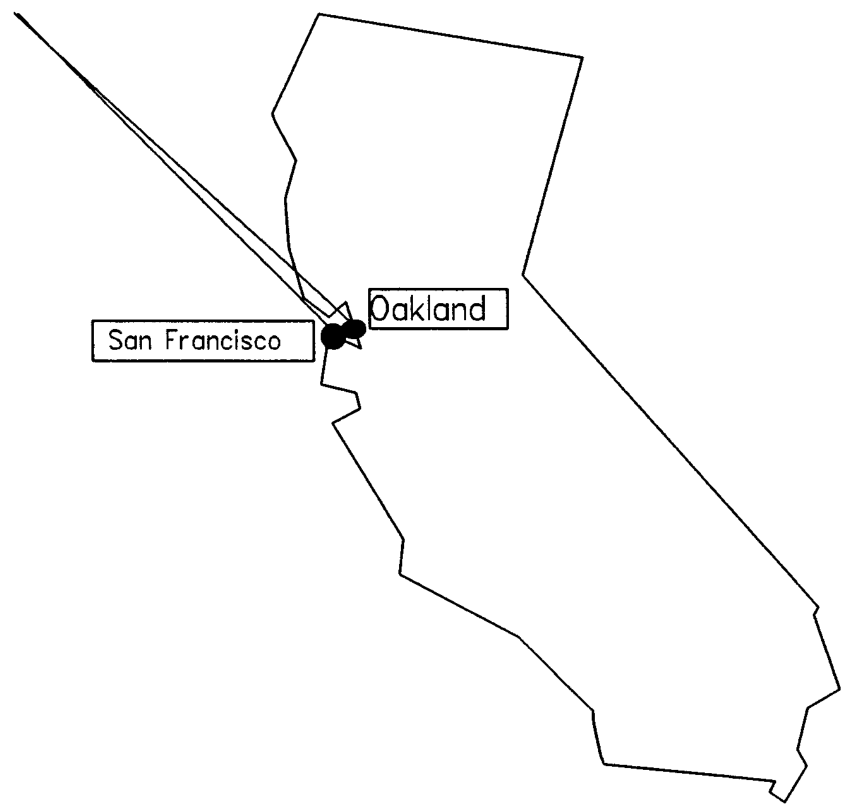


Unacknowledged vs. Acknowledged Ballast
Bulkers

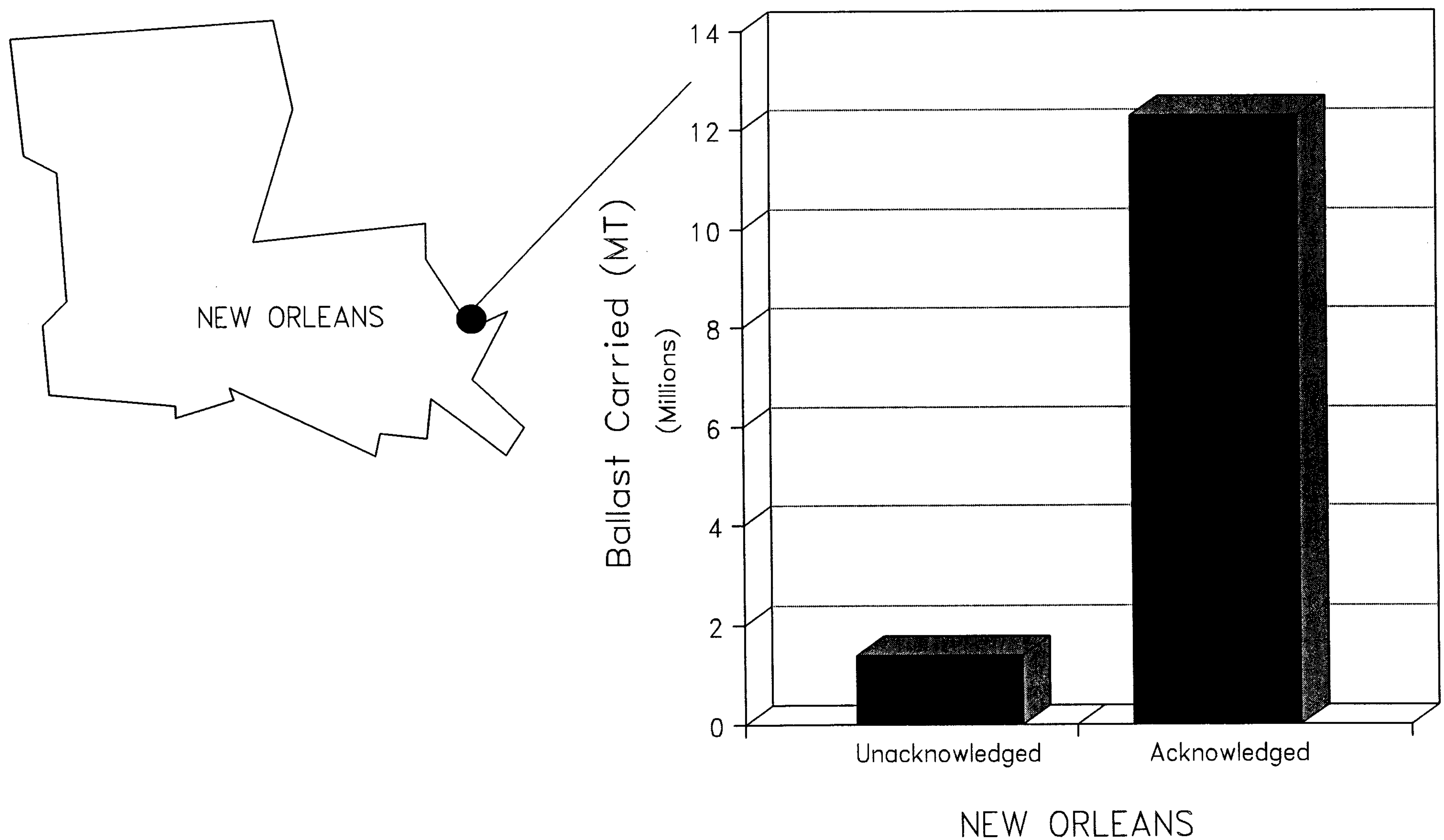


Unacknowledged vs. Acknowledged Ballast
Bulkers

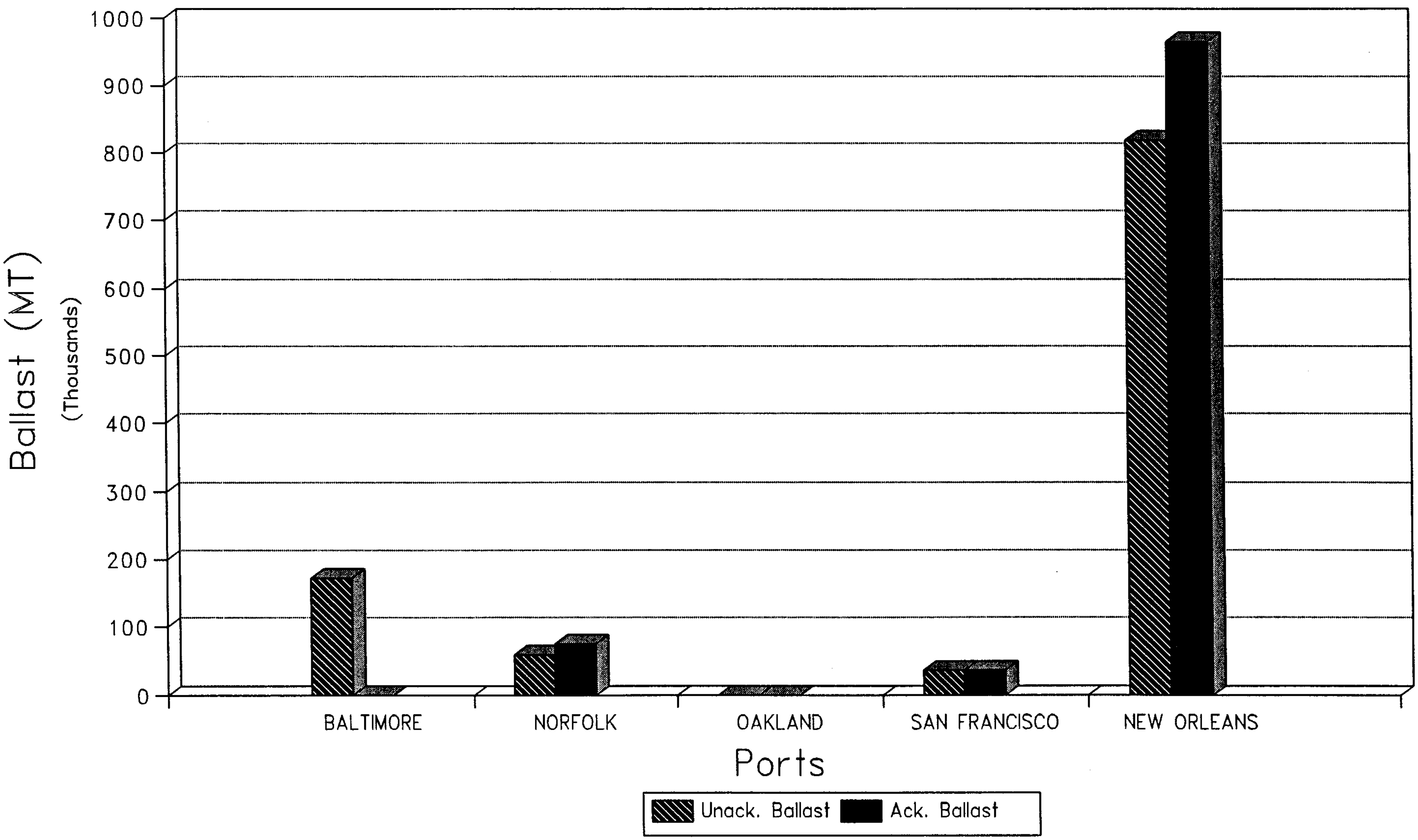




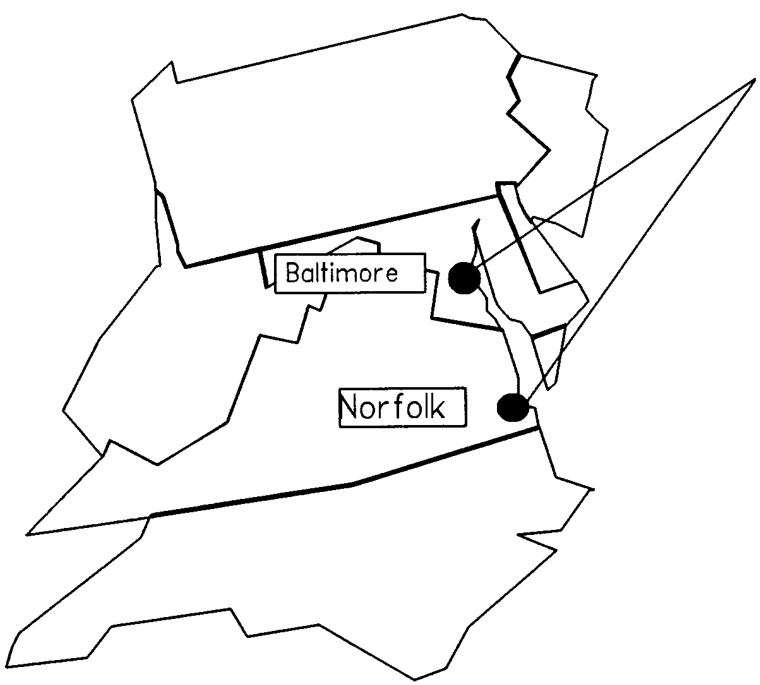
Unacknowledged vs. Acknowledged Ballast
Bulkers

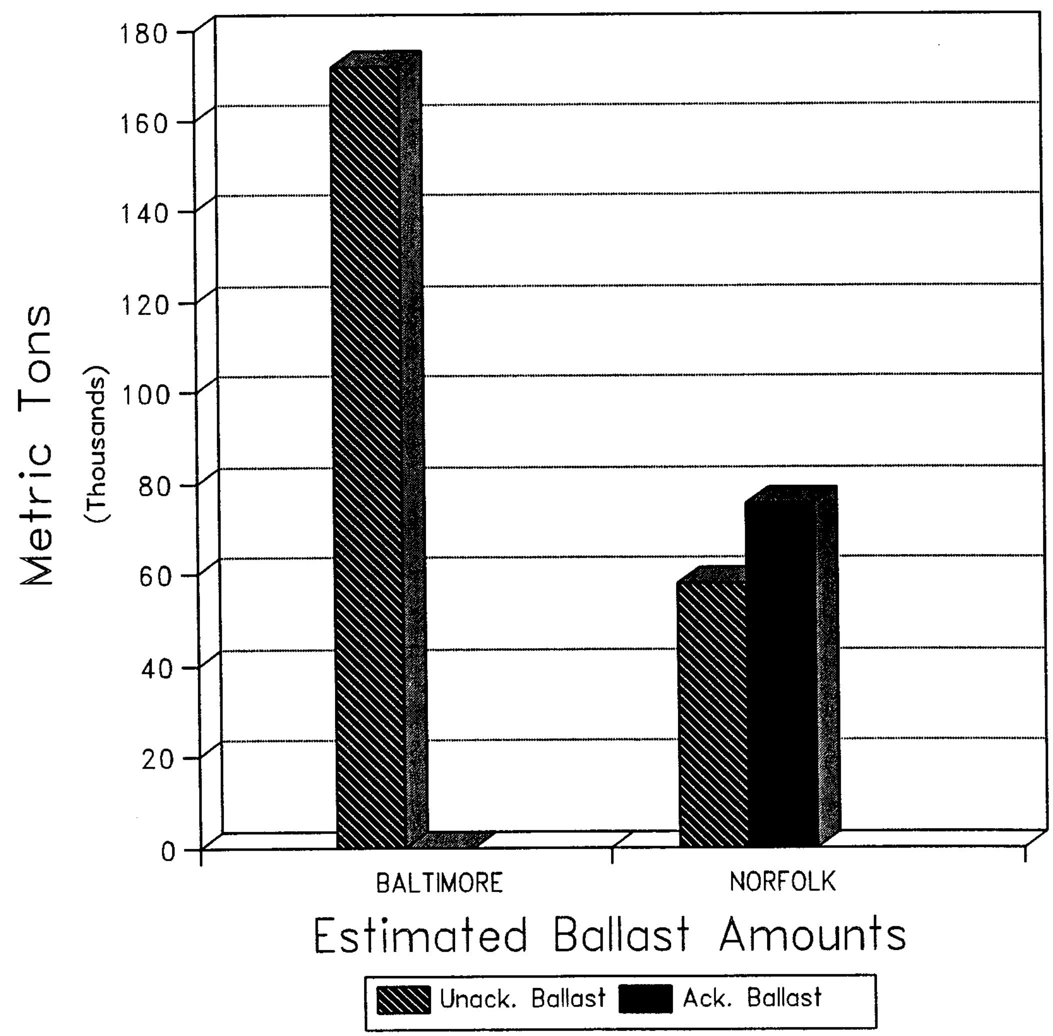


Unacknowledged vs. Acknowledged Ballast
Tankers

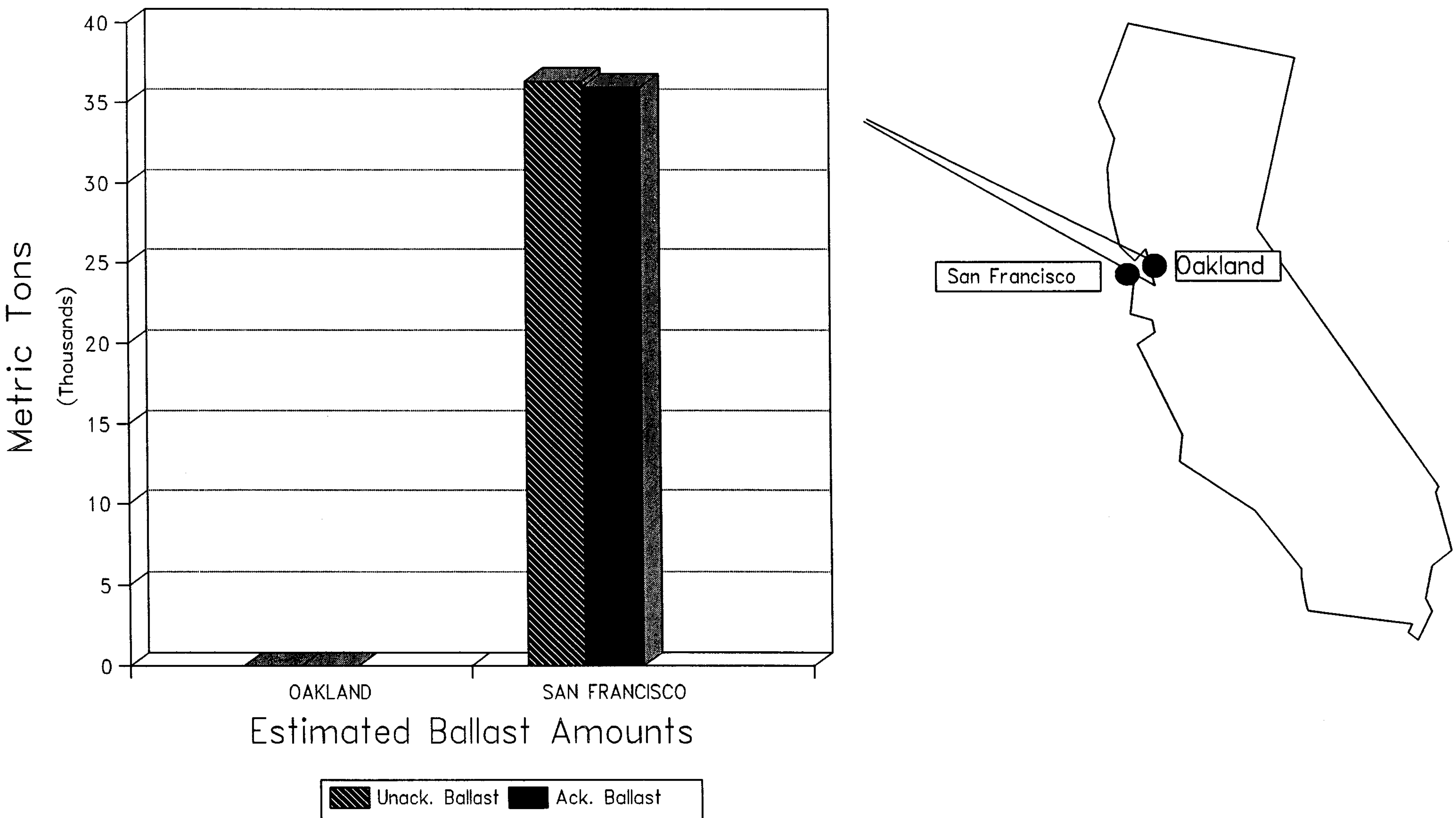


Unacknowledged vs. Acknowledged Ballast
Tankers

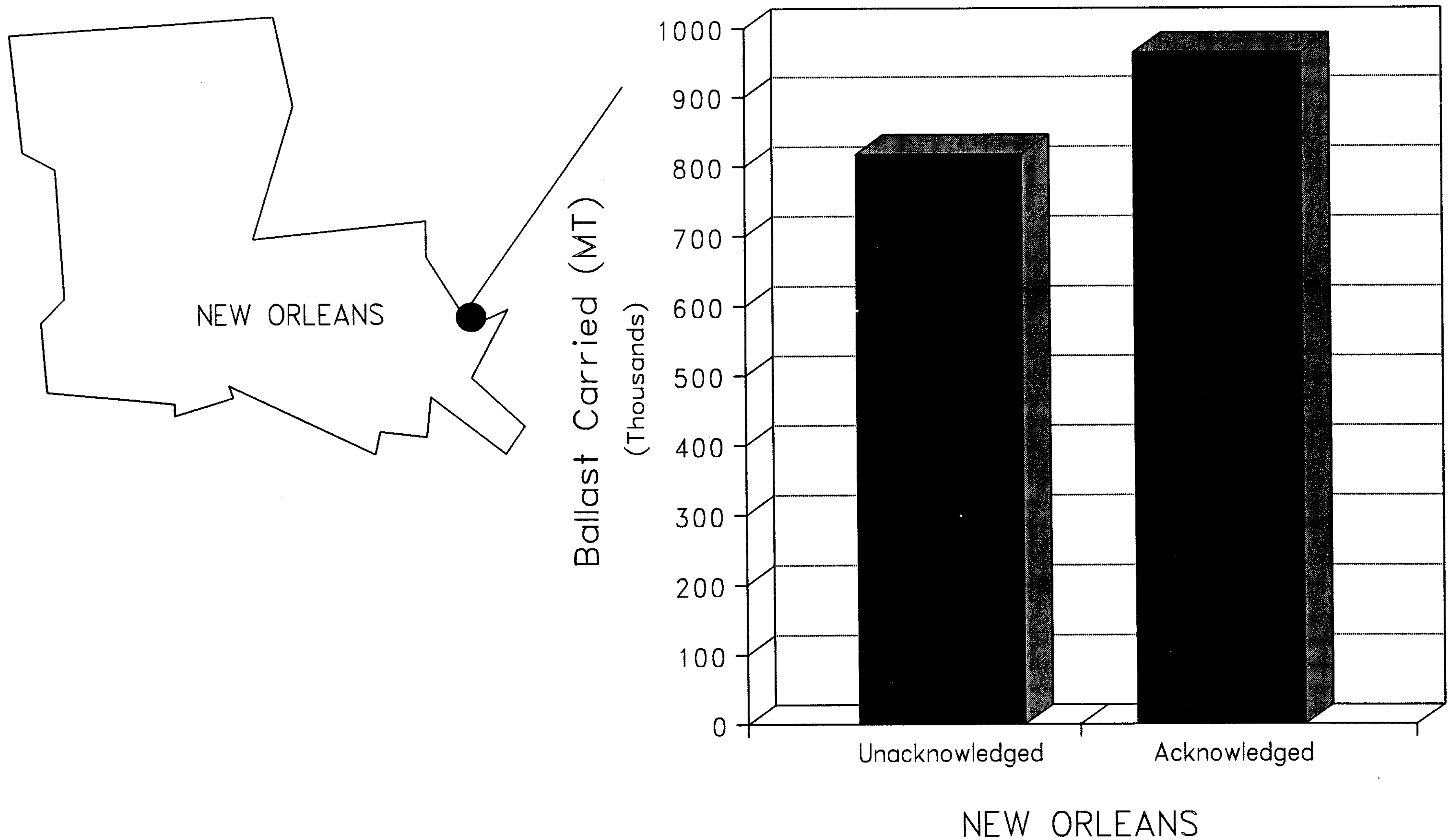




Unacknowledged vs. Acknowledged Ballast
Tankers



Unacknowledged vs. Acknowledged Ballast Tankers



APPENDIX G

LAST PORT OF CALL (LPOC) BY FAO REGION FOR FOREIGN SHIPS IN BALLAST FOR NABISS PORTS

FAO REGIONS OF THE WORLD

A	Northwest Atlantic
B	Northeast Atlantic
C	Mediterranean and Black Sea
D	Northwest Pacific
E	Northeast Pacific
F	Eastern Central Atlantic
G	Western Central Atlantic
H	Indian Ocean
I	Western Central Pacific
J	Eastern Central Pacific
K	Southwest Pacific
L	Southeast Pacific
M	Southwest Atlantic
N	Southeast Atlantic
P	Australia (*)
Q	Great Lakes (*)

GREAT LAKES		Q					
ATLANTIC	A	B	F	G	M	N	
MEDITERRANEAN/BLACK SEA	C						
INDIAN		H					
PACIFIC/AUSTRALASIA	D	E	I	J	K	L	P

(*) **NOTE:**

AUSTRALIA and GREAT LAKES are *not FAO regions.* Australia is designated here as a separate region because Census data are not sufficiently detailed to permit us to determine to which FAO region the LPOC should be assigned. The Great Lakes are designated here as a separate region because foreign shipping comes from this region.

APPENDIX G

LAST PORT OF CALL (LPOC) FOR SHIPS IN BALLAST FROM FOREIGN PORTS

Boston and New York
Baltimore, Norfolk, Charleston
Savannah and Miami
Tampa and New Orleans
Houston and Galveston
San Diego, Long Beach, Los Angeles
Oakland, San Francisco, Portland
Tacoma, Seattle, Anchorage
Honolulu

LAST PORT OF CALL (LPOC) BY FAO REGION

Baltimore: Foreign in Ballast, Foreign in Cargo, Domestic/Ballast, Domestic/Cargo

LPOC by FAO region for ships from foreign ports: Baltimore

Norfolk: Foreign in Ballast, Foreign in Cargo, Domestic/Ballast, Domestic/Cargo

LPOC by FAO region for ships from foreign ports: Norfolk

New Orleans: Foreign in Ballast, Foreign in Cargo, Domestic/Ballast, Domestic/Cargo

LPOC by FAO region for ships from foreign ports: New Orleans

San Francisco: Foreign in Ballast, Foreign/Cargo, Domestic/Ballast, Domestic/Cargo

LPOC by FAO region for ships from foreign ports: San Francisco

Oakland: Foreign in Ballast, Foreign in Cargo, Domestic/Ballast, Domestic/Cargo

LPOC by FAO region for ships from foreign ports: Oakland

LPOC by FAO Region for Ships in Ballast From Foreign Ports

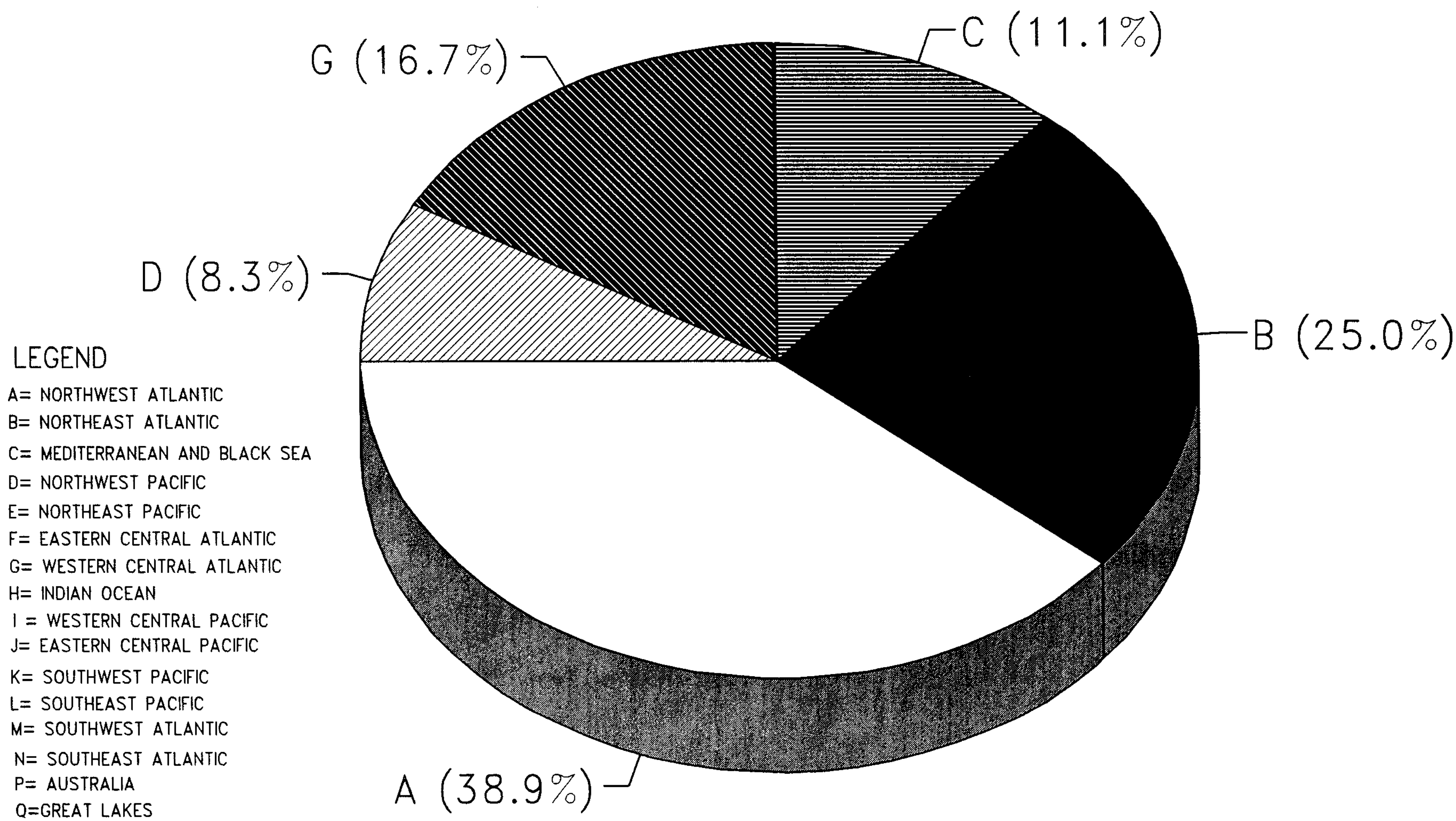
Boston, MA

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHWEST ATLANTIC	14	38.89
NORTHEAST ATLANTIC	9	25.00
WESTERN CENTRAL ATLANTIC	6	16.67
MEDITERRANEAN AND BLACK SEA	4	11.11
NORTHWEST PACIFIC	3	8.33
TOTAL	36	100

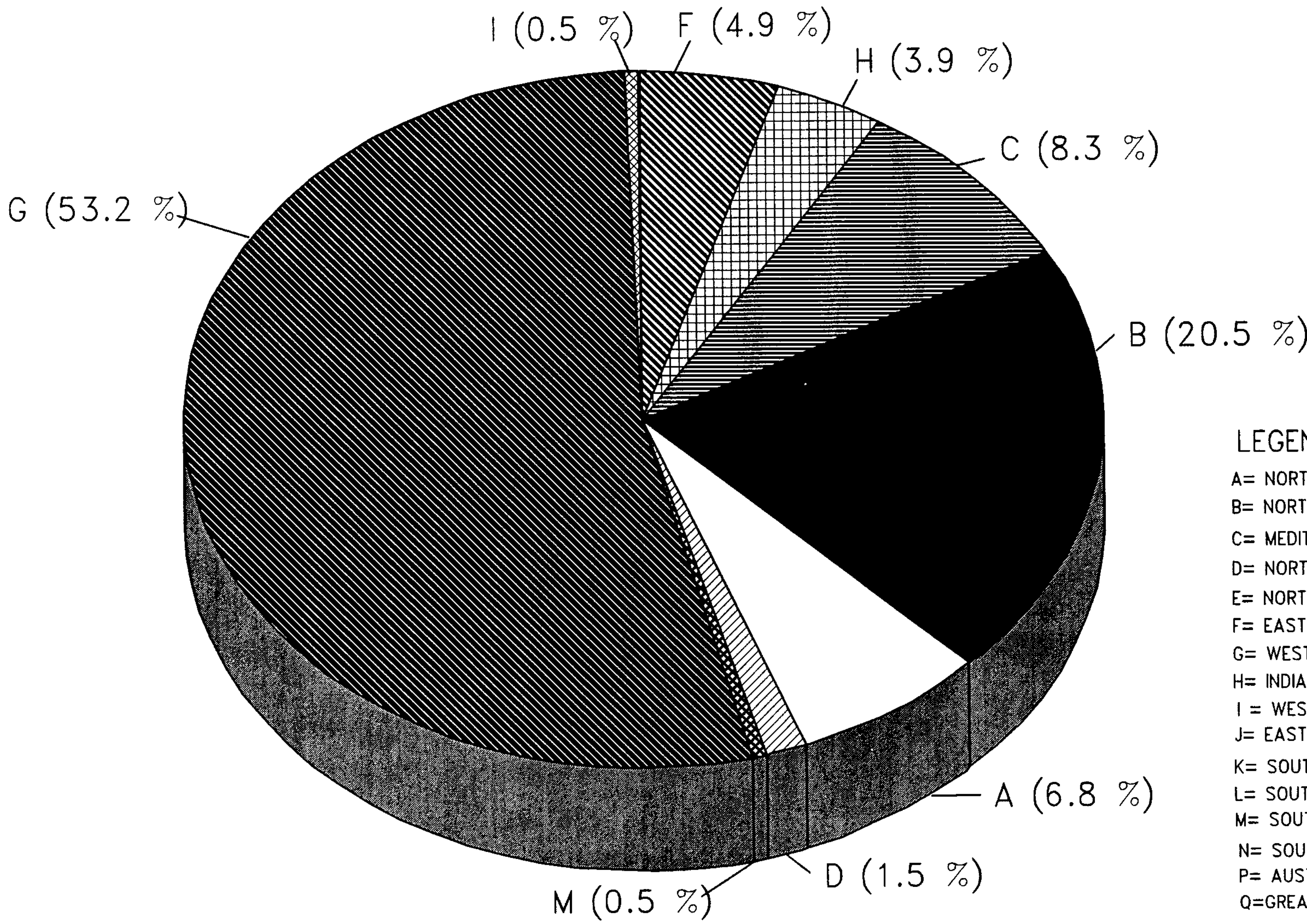
New York, NY

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
WESTERN CENTRAL ATLANTIC	109	53.17
NORTHEAST ATLANTIC	42	20.49
MEDITERRANEAN AND BLACK SEA	17	8.29
NORTHWEST ATLANTIC	14	6.83
EASTERN CENTRAL ATLANTIC	10	4.88
INDIAN OCEAN	8	3.90
NORTHWEST PACIFIC	3	1.46
WESTERN CENTRAL PACIFIC	1	0.49
SOUTHWEST ATLANTIC	1	0.49
TOTAL	205	100

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–BOSTON



LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–NEW YORK



LEGEND
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LPOC by FAO Region for Ships in Ballast From Foreign Ports

Baltimore, MD

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHEAST ATLANTIC	97	47.55
MEDITERRANEAN AND BLACK SEA	50	24.51
NORTHWEST ATLANTIC	20	9.80
WESTERN CENTRAL ATLANTIC	14	6.86
EASTERN CENRTAL ATLANTIC	14	6.86
WESTERN CENTRAL PACIFIC	6	2.94
SOUTHWEST ATLANTIC	2	0.98
NORTHWEST PACIFIC	1	0.49
TOTAL	204	100

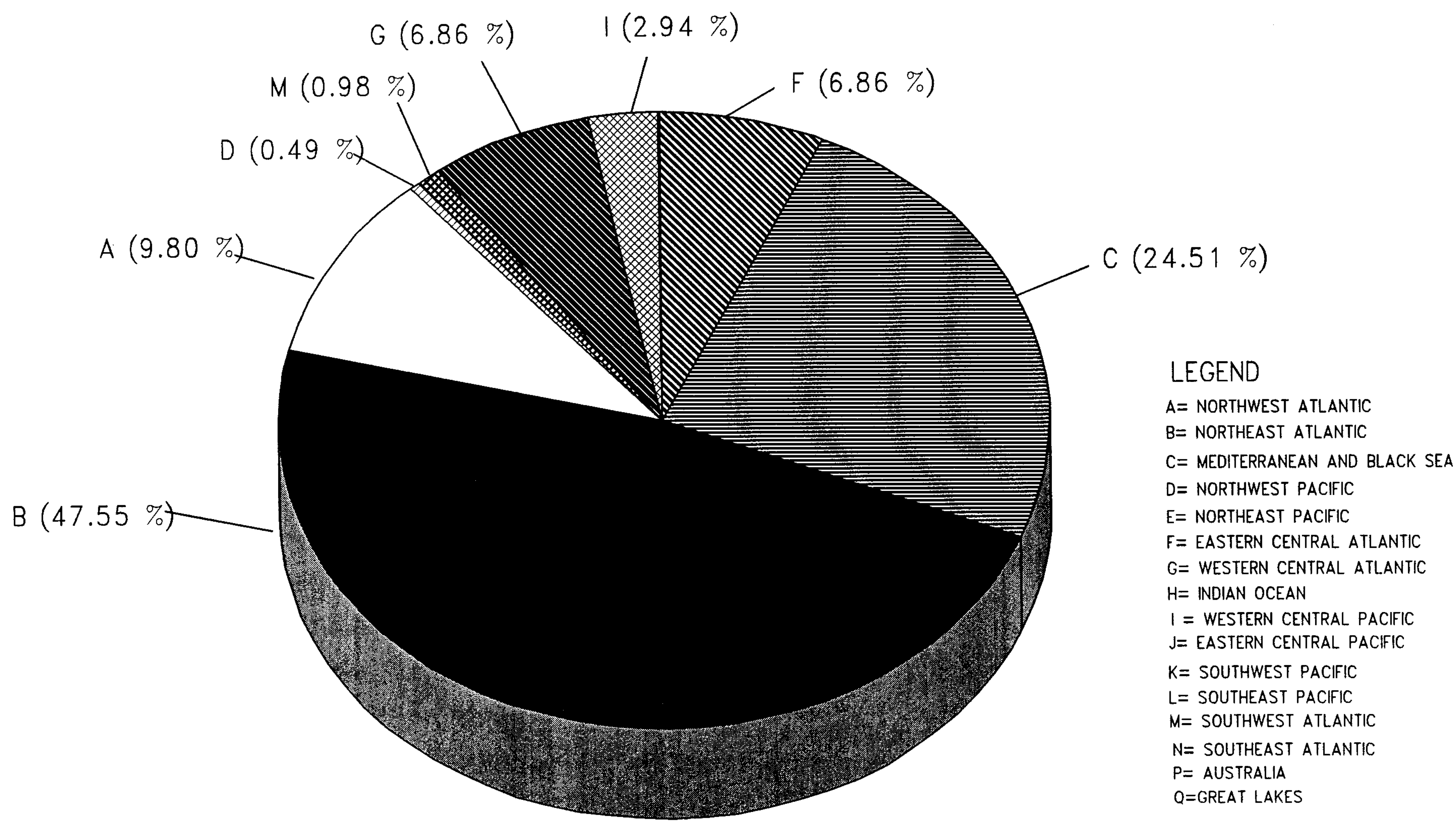
Norfolk, VA

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHEAST ATLANTIC	254	59.76
MEDITERRANEAN AND BLACK SEA	102	24.00
EASTERN CENTRAL ATLANTIC	24	5.65
WESTERN CENTRAL ATLANTIC	24	5.65
NORTHWEST ATLANTIC	14	3.29
EASTERN CENTRAL PACIFIC	3	0.71
INDIAN OCEAN	2	0.47
SOUTHEAST ATLANTIC	2	0.47
TOTAL	425	100

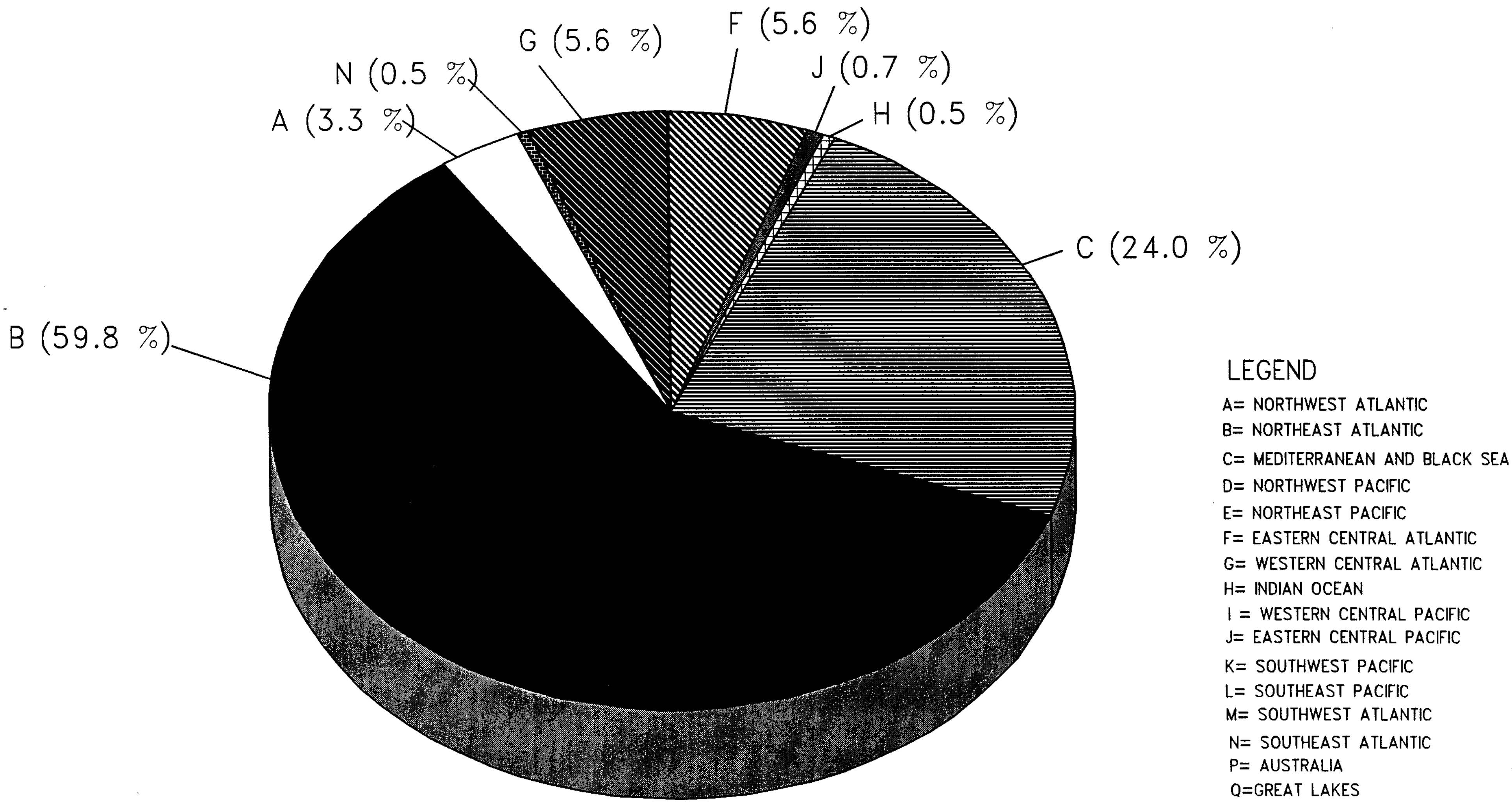
Charleston, SC

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHEAST ATLANTIC	21	42
WESTERN CENTRAL ATLANTIC	13	26
MEDITERRANEAN AND BLACK SEA	7	14
EASTERN CENTRAL ATLANTIC	3	6
NORTHWEST ATLANTIC	3	6
INDIAN OCEAN	3	6
TOTAL	50	100

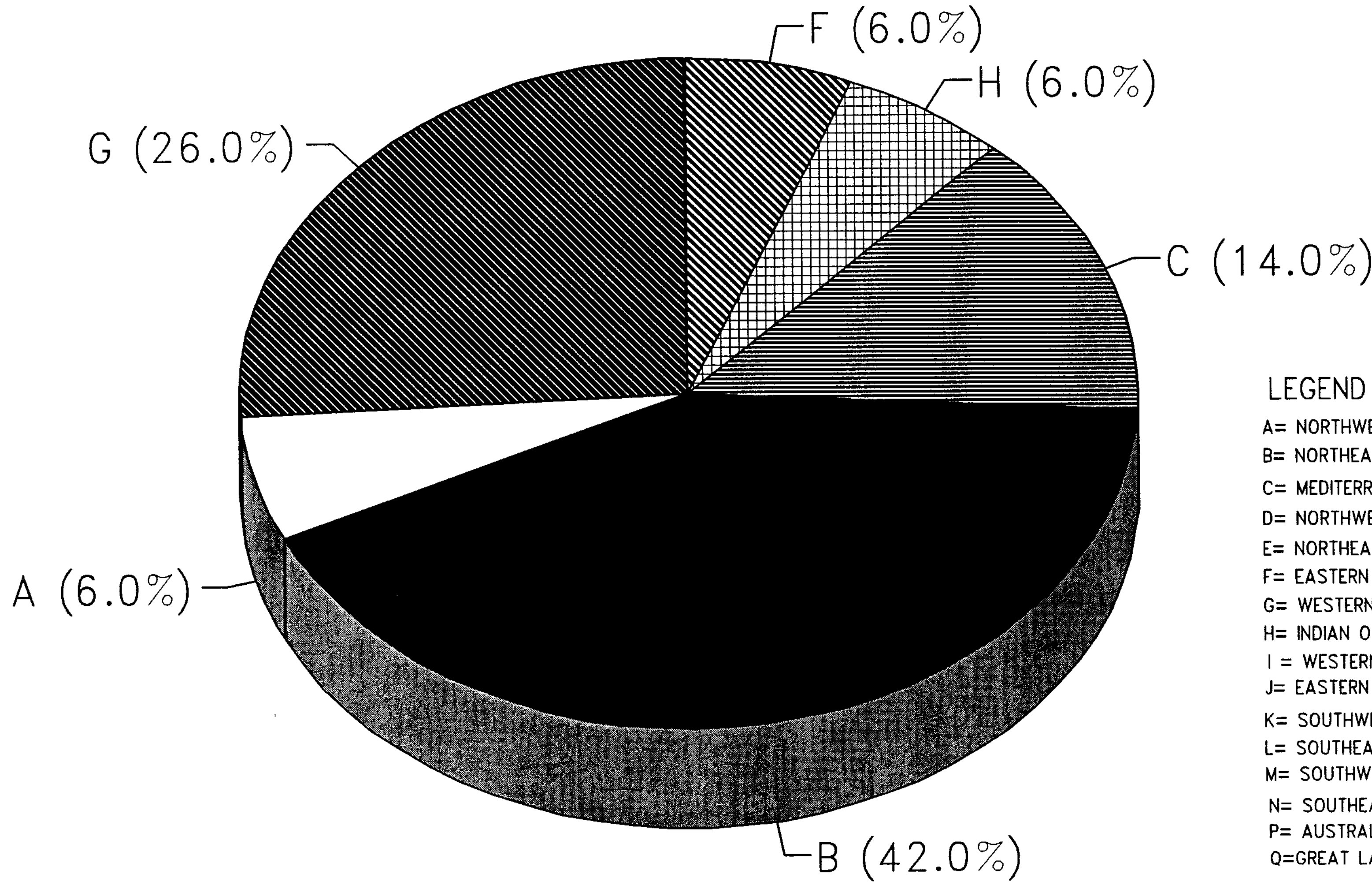
LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–BALTIMORE



LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–NORFOLK



LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–CHARLESTON



LEGEND
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LPOC by FAO Region for Ships in Ballast From Foreign Ports

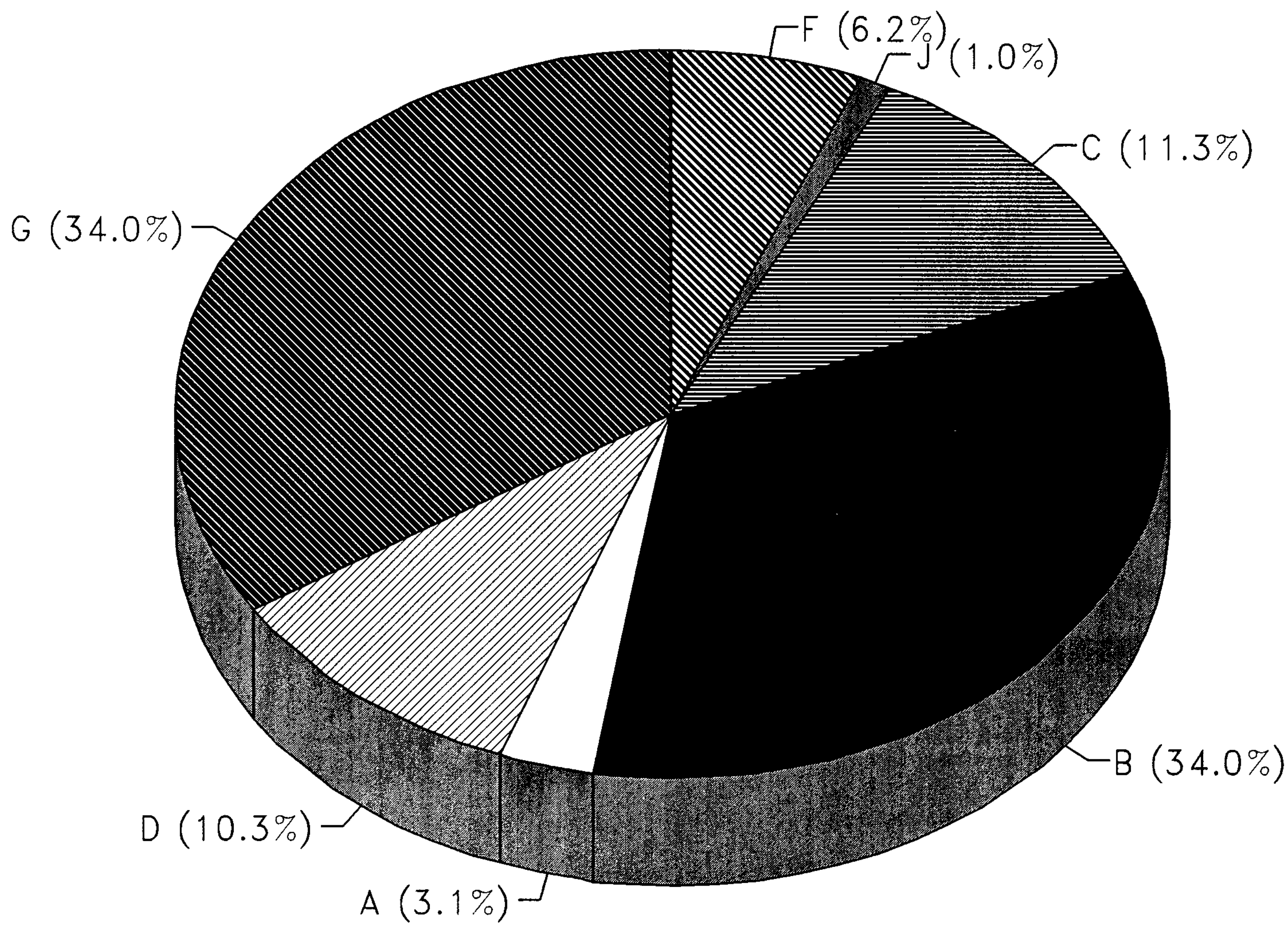
Savannah, GA

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHEAST ATLANTIC	33	34.02
WESTERN CENTRAL ATLANTIC	33	34.02
MEDITERRANEAN AND BLACK SEA	11	11.34
NORTHWEST PACIFIC	10	10.31
EASTERN CENTRAL ATLANTIC	6	6.19
NORTHWEST ATLANTIC	3	3.09
EASTERN CENTRAL PACIFIC	1	1.03
TOTAL	97	100

Miami, FL

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
WESTERN CENTRAL ATLANTIC	2641	99.21
NORTHEAST ATLANTIC	5	0.19
NORTHWEST ATLANTIC	4	0.15
MEDITERRANEAN AND BLACK SEA	4	0.15
SOUTHEAST PACIFIC	3	0.11
EASTERN CENTRAL PACIFIC	2	0.08
WESTERN CENTRAL PACIFIC	1	0.04
EASTERN CENTRAL ATLANTIC	1	0.04
SOUTHWEST ATLANTIC	1	0.04
TOTAL	2662	100

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–SAVANNAH

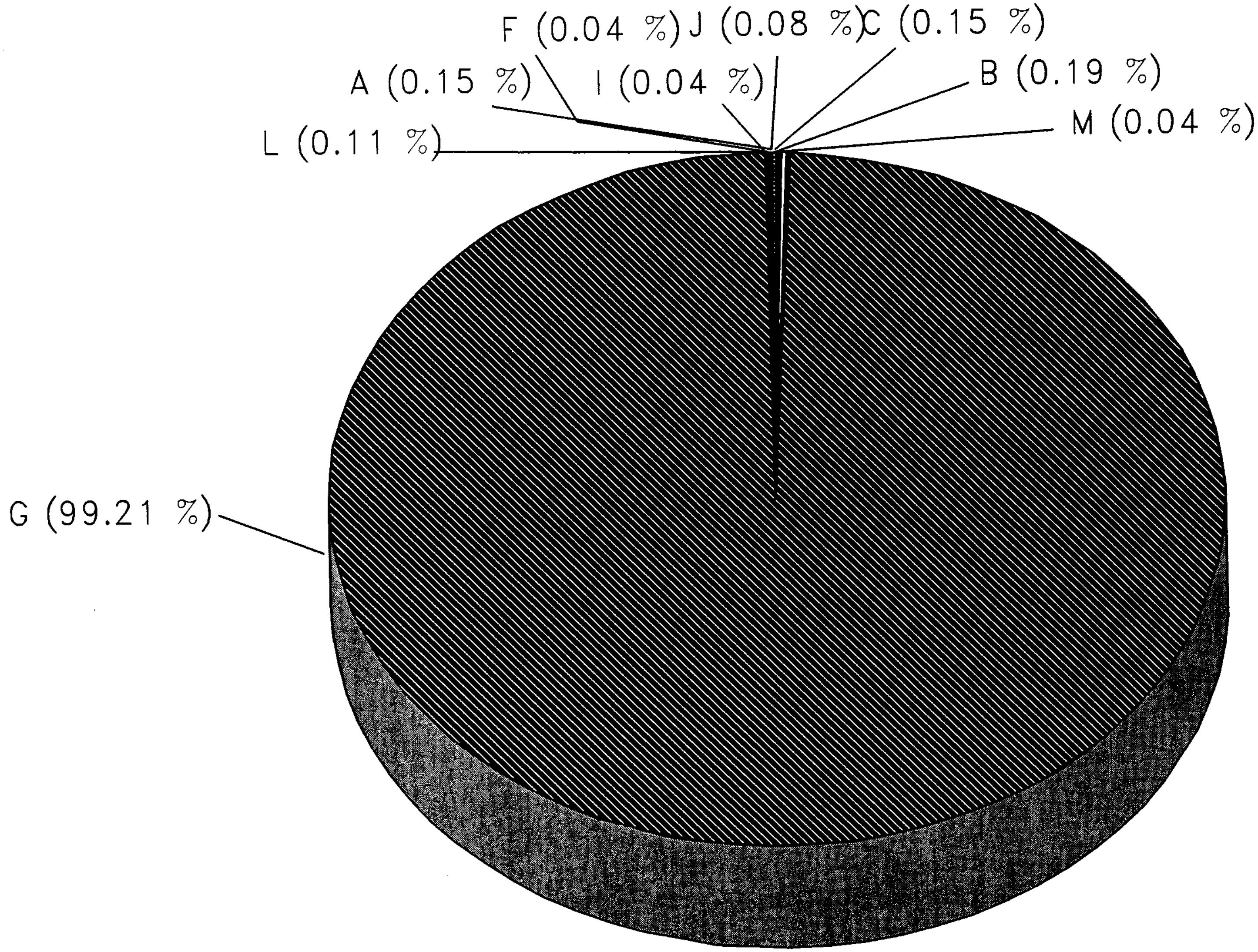


LEGEND

A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS—MIAMI



LEGEND

A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LPOC by FAO Region for Ships in Ballast From Foreign Ports

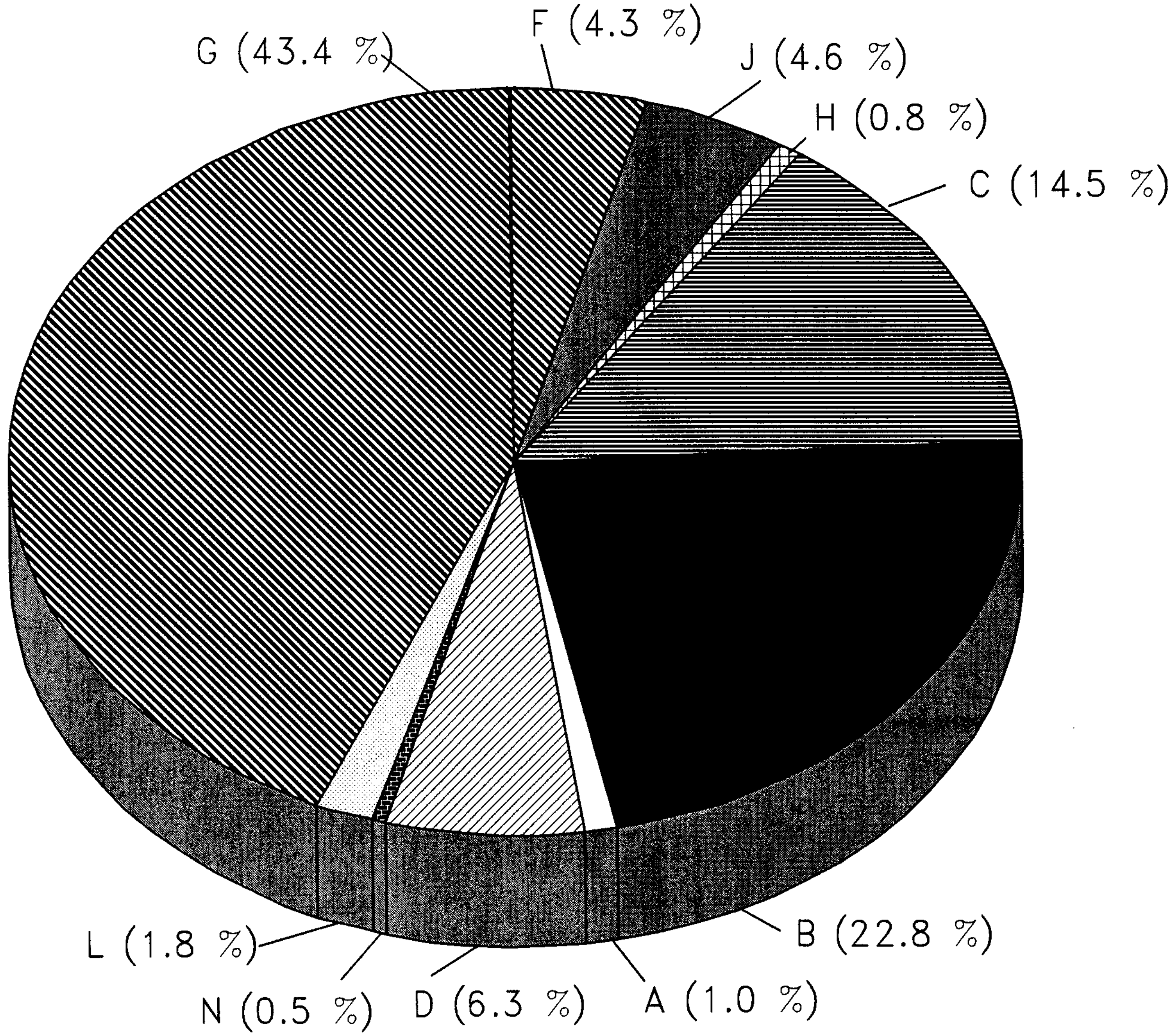
Tampa, FL

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
WESTERN CENTRAL ATLANTIC	171	43.40
NORTHEAST ATLANTIC	90	22.84
MEDITERRANEAN AND BLACK SEA	57	14.47
NORTHWEST PACIFIC	25	6.35
EASTERN CENTRAL PACIFIC	18	4.57
EASTERN CENTRAL ATLANTIC	17	4.31
SOUTHEAST PACIFIC	7	1.78
NORTHWEST ATLANTIC	4	1.02
INDIAN OCEAN	3	0.76
SOUTHEAST ATLANTIC	2	0.51
TOTAL	394	100

New Orleans, LA

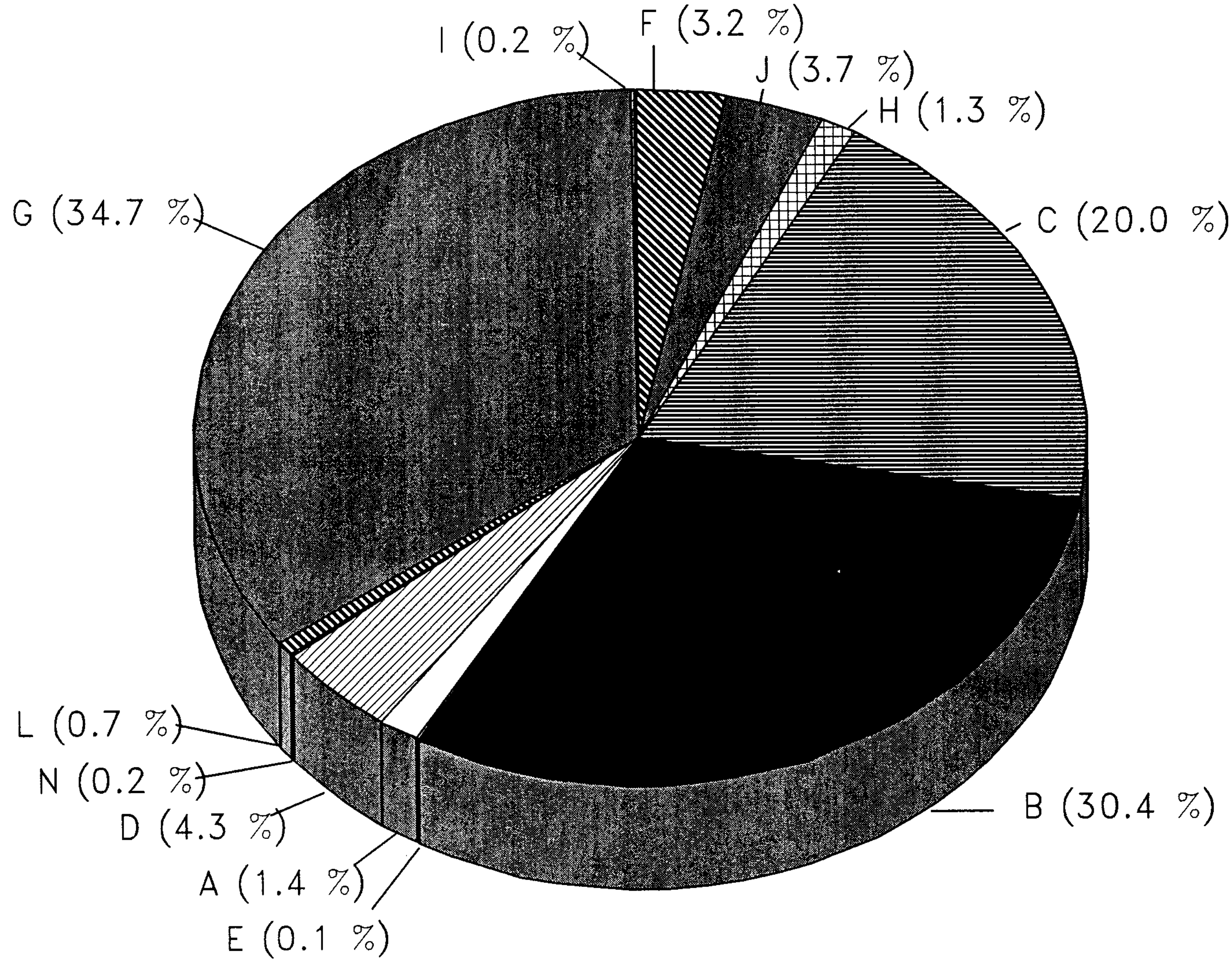
FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
WESTERN CENTRAL ATLANTIC	437	34.68
NORTHEAST ATLANTIC	383	30.40
MEDITERRANEAN AND BLACK SEA	252	20.00
NORTHWEST PACIFIC	54	4.29
EASTERN CENTRAL PACIFIC	46	3.65
EASTERN CENTRAL ATLANTIC	40	3.17
NORTHWEST ATLANTIC	18	1.43
INDIAN OCEAN	16	1.27
SOUTHEAST PACIFIC	9	0.71
WESTERN CENTRAL PACIFIC	2	0.16
SOUTHEAST ATLANTIC	2	0.16
NORTHEAST PACIFIC	1	0.08
TOTAL	1260	100

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–TAMPA



LEGEND
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS—NEW ORLEANS



LEGEND
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LPOC by FAO Region for Ships in Ballast From Foreign Ports

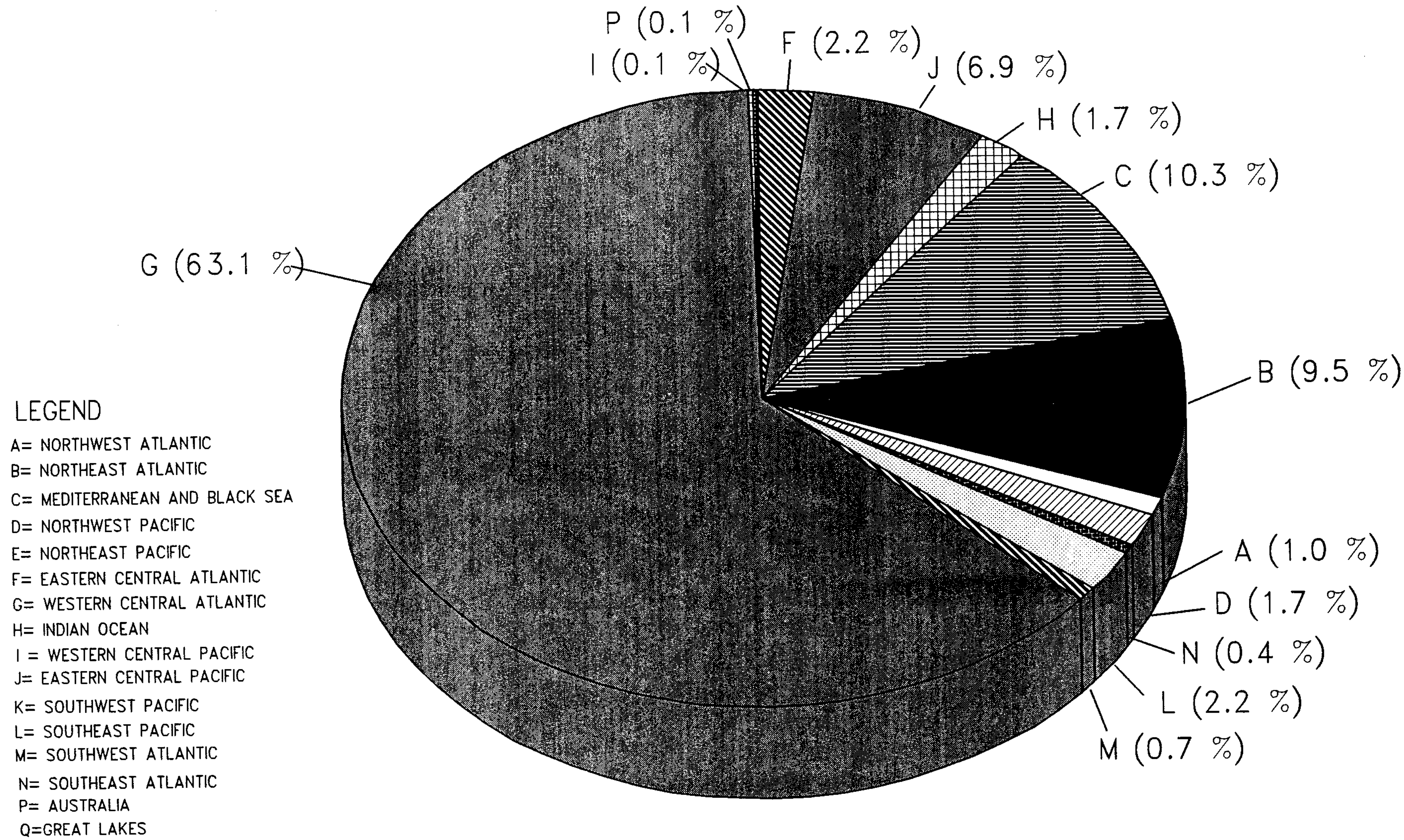
Houston, TX

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
WESTERN CENTRAL ATLANTIC	439	63.07
MEDITERRANEAN AND BLACK SEA	72	10.34
NORTHEAST ATLANTIC	66	9.48
EASTERN CENTRAL PACIFIC	48	6.90
SOUTHEAST PACIFIC	15	2.16
EASTERN CENTRAL ATLANTIC	15	2.16
INDIAN OCEAN	13	1.87
NORTHWEST PACIFIC	12	1.72
NORTHWEST ATLANTIC	7	1.01
SOUTHWEST ATLANTIC	5	0.72
SOUTHEAST ATLANTIC	3	0.43
WESTERN CENTRAL PACIFIC	1	0.14
TOTAL	696	100

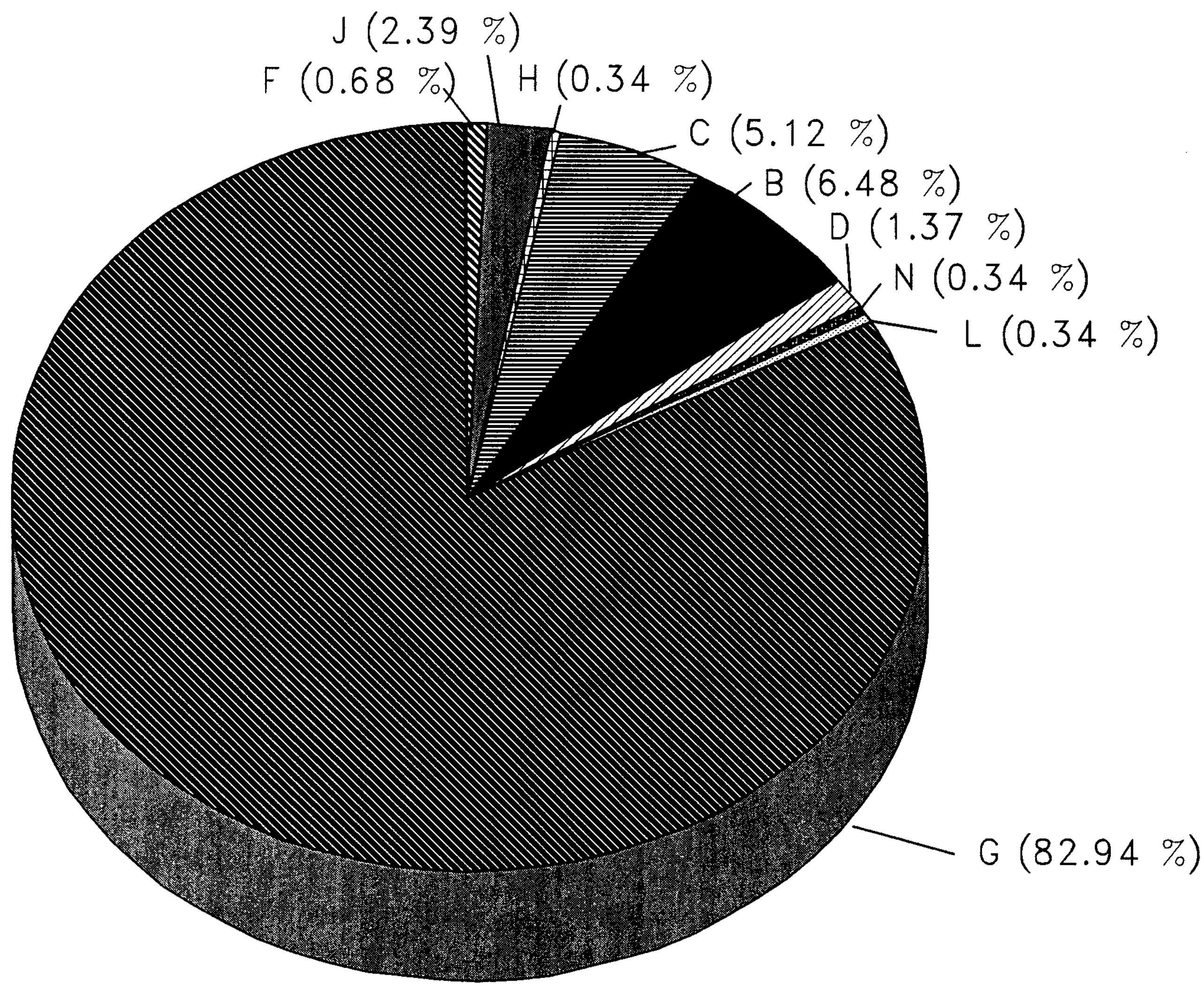
Galveston, TX

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
WESTERN CENTRAL ATLANTIC	243	82.94
NORTHEAST ATLANTIC	19	6.48
MEDITERRANEAN AND BLACK SEA	15	5.12
EASTERN CENTRAL PACIFIC	7	2.39
NORTHWEST PACIFIC	4	1.37
EASTERN CENTRAL ATLANTIC	2	0.68
SOUTHEAST PACIFIC	1	0.34
INDIAN OCEAN	1	0.34
SOUTHEAST ATLANTIC	1	0.34
TOTAL	293	100

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–HOUSTON



LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS—GALVESTON



LEGEND

A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LPOC by FAO Region for Ships in Ballast From Foreign Ports

San Diego, CA

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
EASTERN CENTRAL PACIFIC	637	98.00
WESTERN CENTRAL ATLANTIC	8	1.23
NORTHEAST PACIFIC	3	0.46
SOUTHWEST PACIFIC	1	0.15
NORTHWEST PACIFIC	1	0.15
TOTAL	650	100

Long Beach, CA

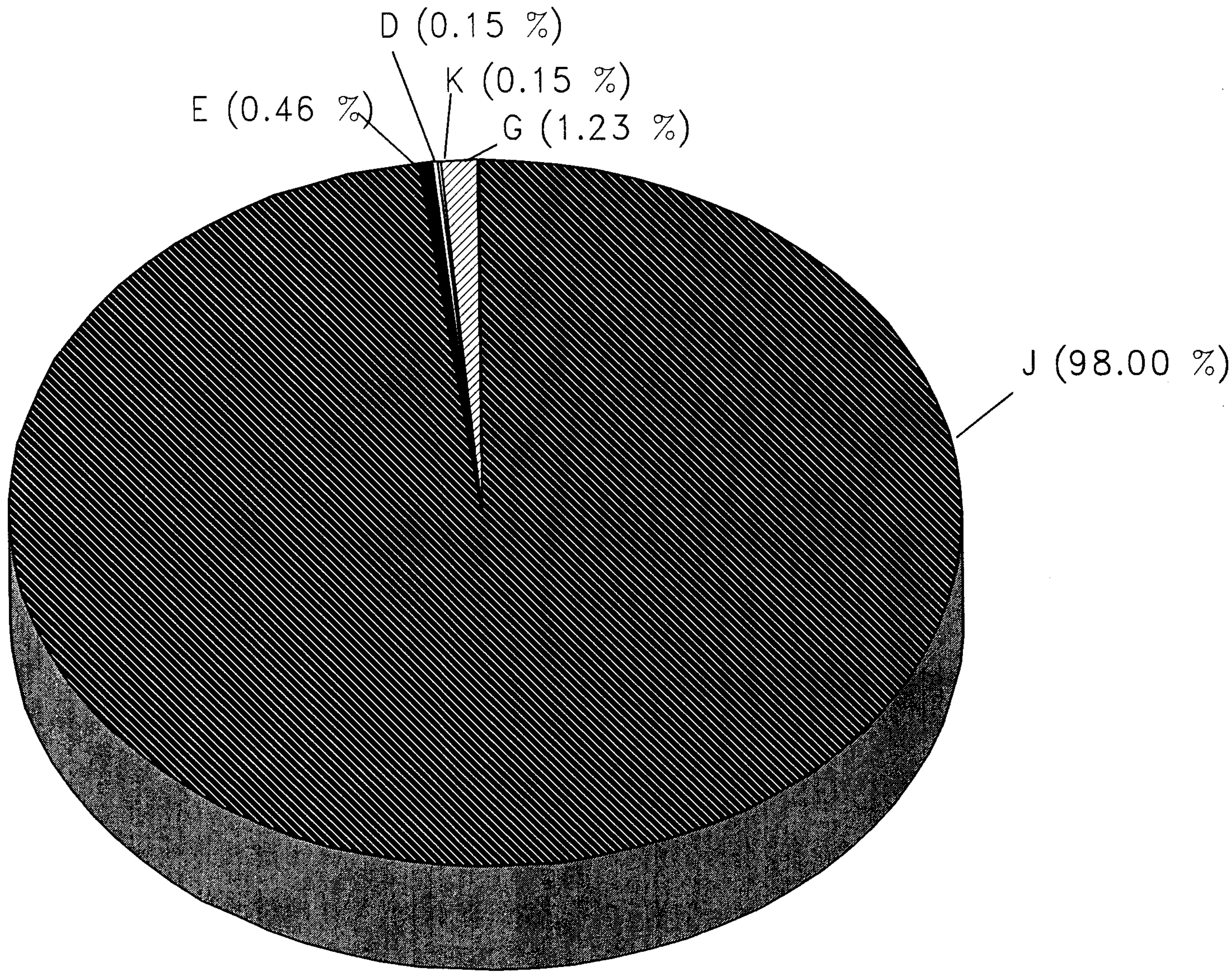
FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHWEST PACIFIC	150	68.18
EASTERN CENTRAL PACIFIC	61	27.73
SOUTHWEST PACIFIC	2	0.91
WESTERN CENTRAL ATLANTIC	2	0.91
MEDITERRANEAN AND BLACK SEA	2	0.91
NORTHEAST PACIFIC	2	0.91
NORTHEAST ATLANTIC	1	0.45
TOTAL	220	100

Los Angeles, CA

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
EASTERN CENTRAL PACIFIC	392	73.55
NORTHWEST PACIFIC	98	18.39
GREAT LAKES	17	3.19
SOUTHWEST PACIFIC	9	1.69
WESTERN CENTRAL ATLANTIC	6	1.13
WESTERN CENTRAL PACIFIC	5	0.94
SOUTHEAST PACIFIC	5	0.94
NORTHEAST ATLANTIC	1	0.19
TOTAL	533	100

LAST PORT OF CALL BY FAO REGION

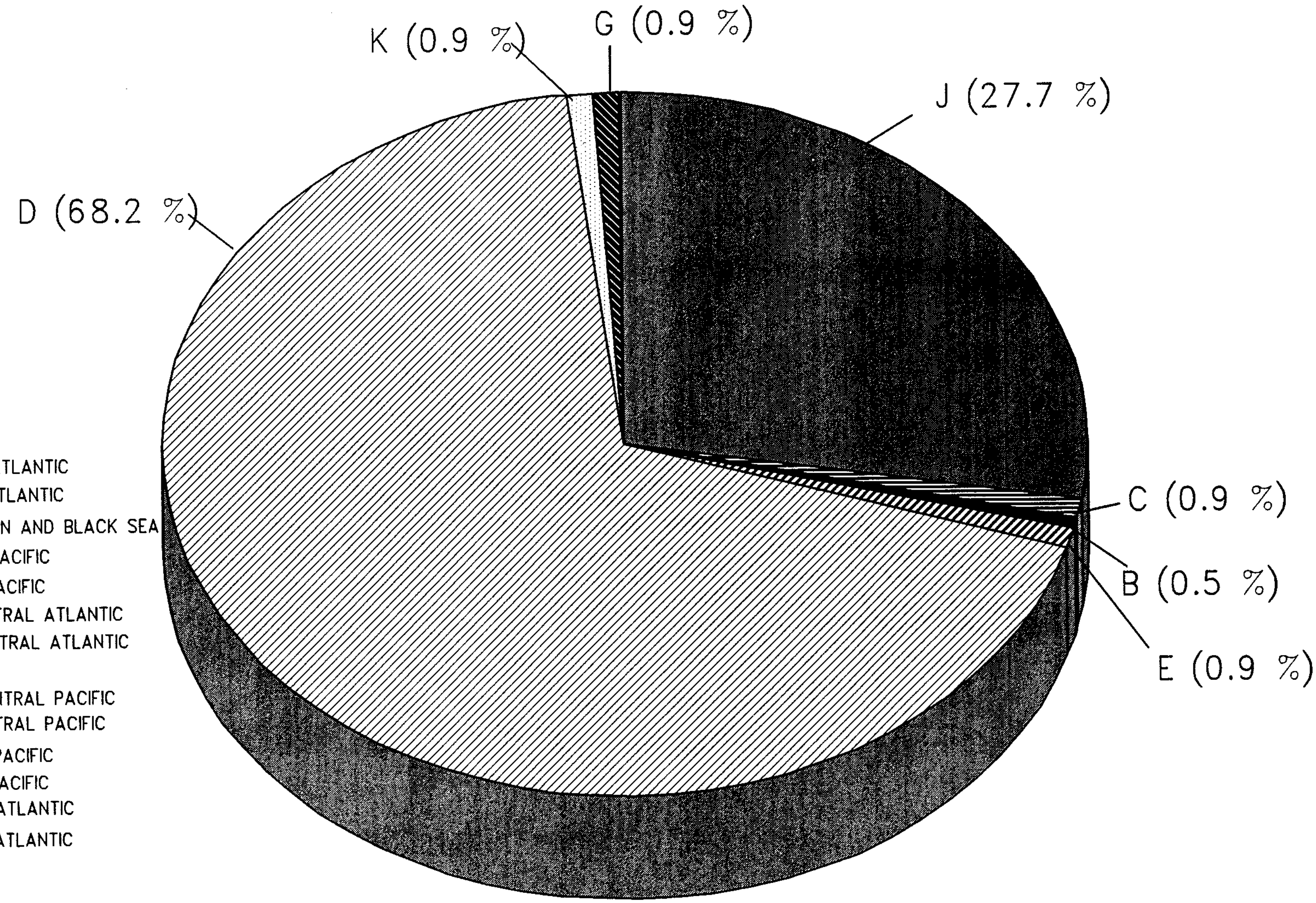
FOR SHIPS FROM FOREIGN PORTS—SAN DIEGO



LEGEND

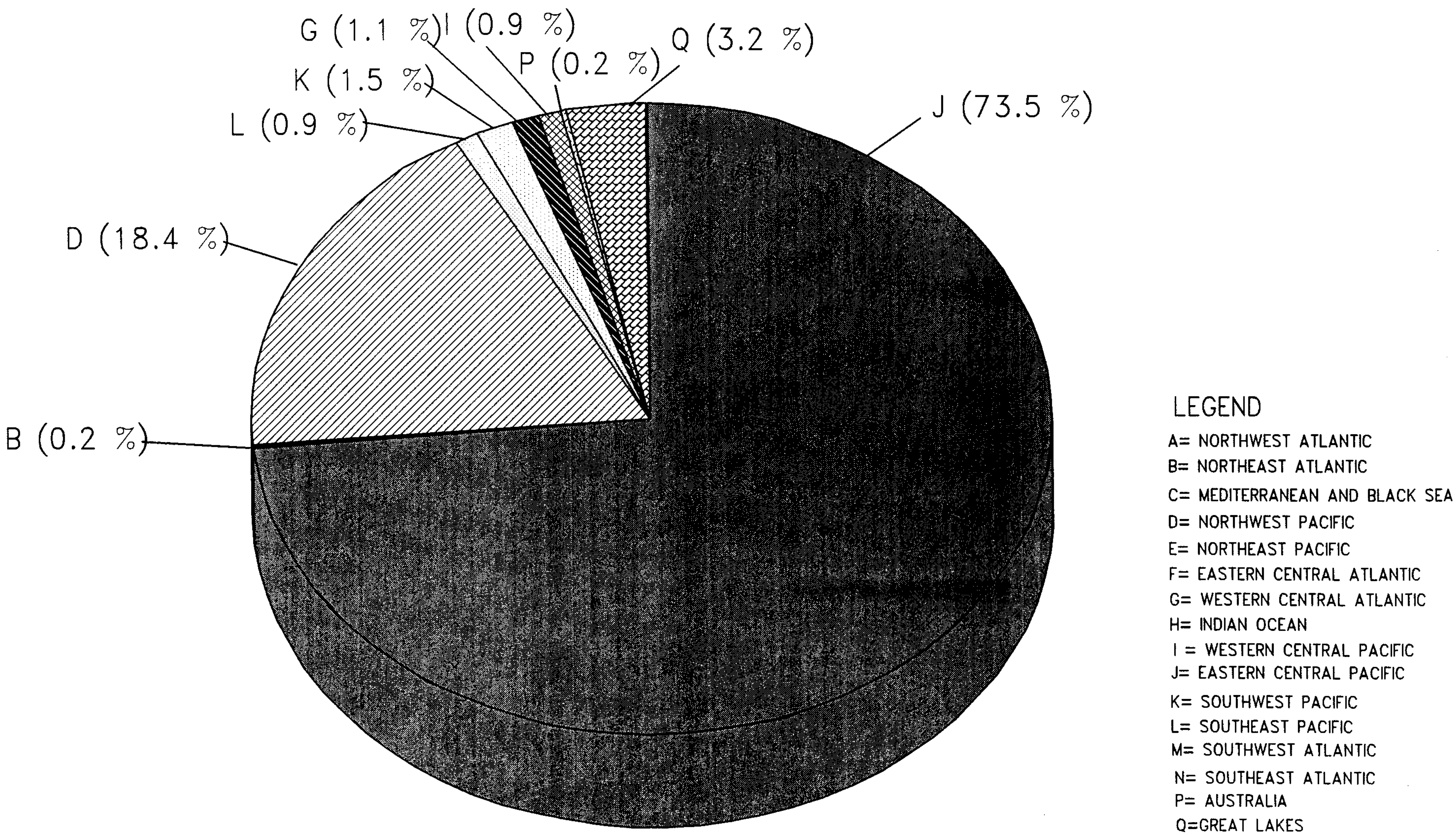
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–LONG BEACH



LEGEND
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–LOS ANGELES



LPOC by FAO Region for Ships in Ballast From Foreign Ports

Oakland, CA

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHWEST PACIFIC	10	71.43
WESTERN CENTRAL PACIFIC	2	14.29
EASTERN CENTRAL PACIFIC	1	7.14
NORTHEAST PACIFIC	1	7.14
TOTAL	14	100

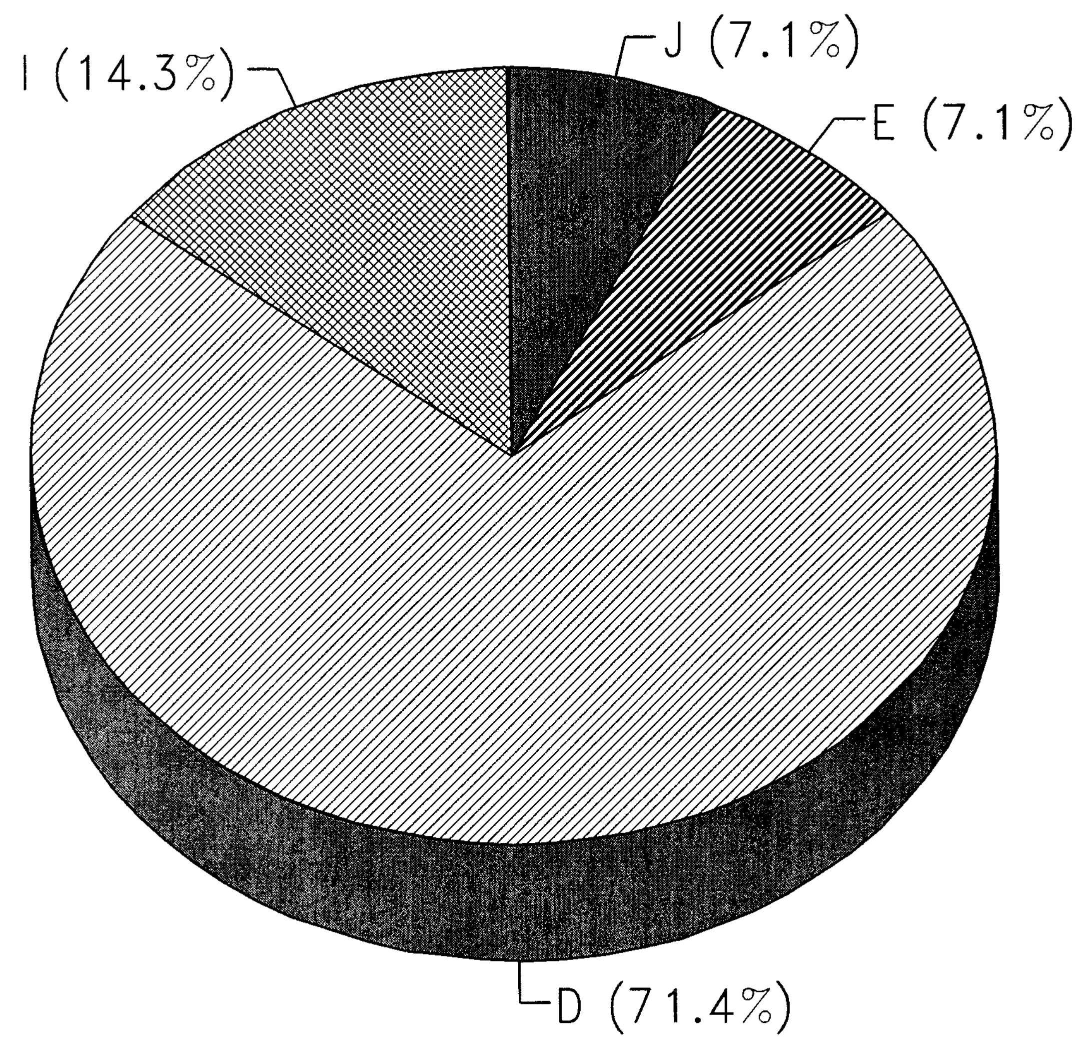
San Francisco, CA

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHEAST PACIFIC	28	63.64
NORTHWEST PACIFIC	9	20.45
EASTERN CENTRAL PACIFIC	6	13.64
WESTERN CENTRAL ATLANTIC	1	2.27
TOTAL	44	100

Portland, OR

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHWEST PACIFIC	216	84.71
NORTHEAST PACIFIC	26	10.20
EASTERN CENTRAL PACIFIC	6	2.35
WESTERN CENTRAL PACIFIC	4	1.57
SOUTHWEST PACIFIC	1	0.39
MEDITERRANEAN AND BLACK SEA	1	0.39
NORTHEAST ATLANTIC	1	0.39
TOTAL	255	100

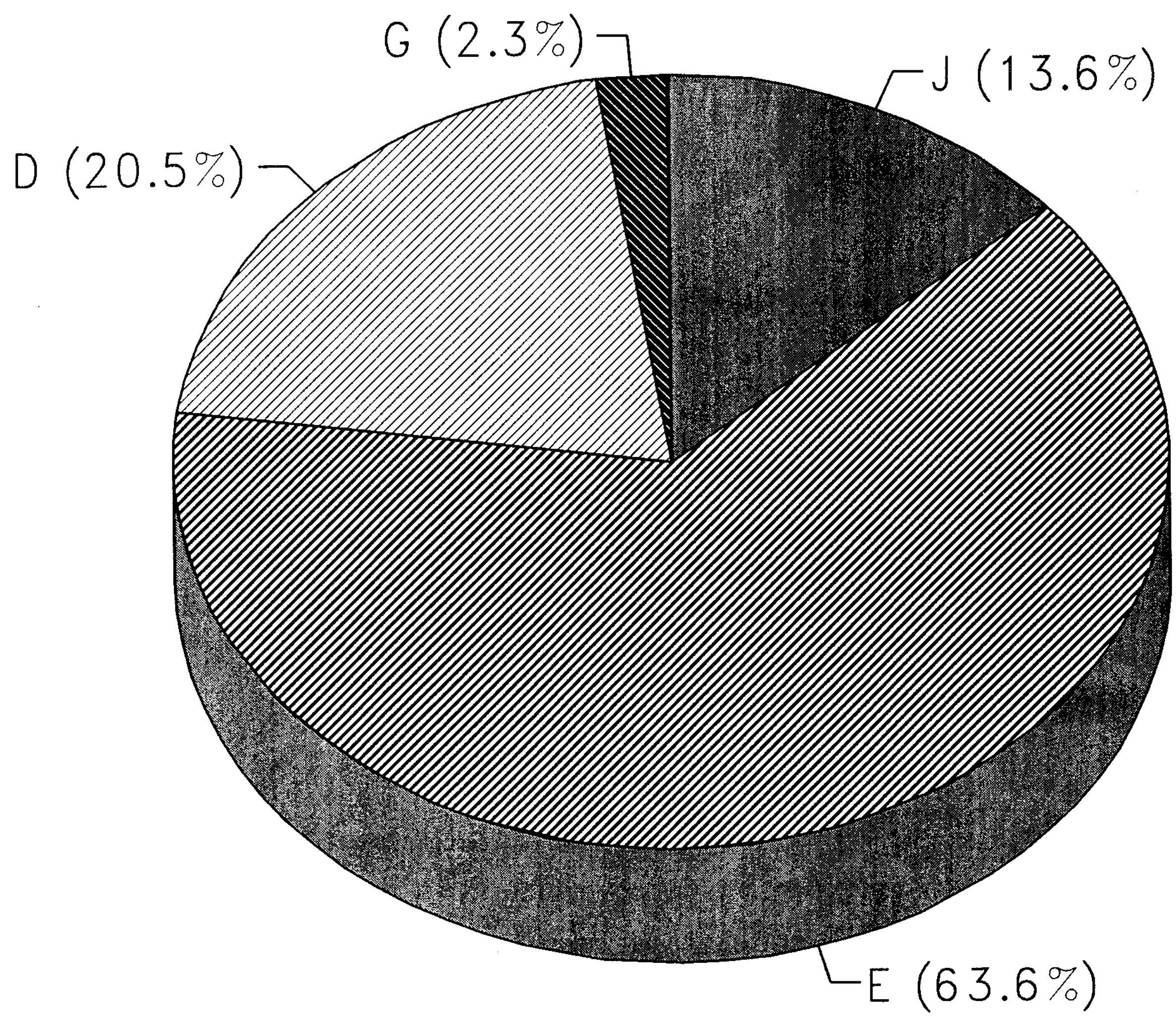
LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–OAKLAND



LEGEND
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS—SAN FRANCISCO

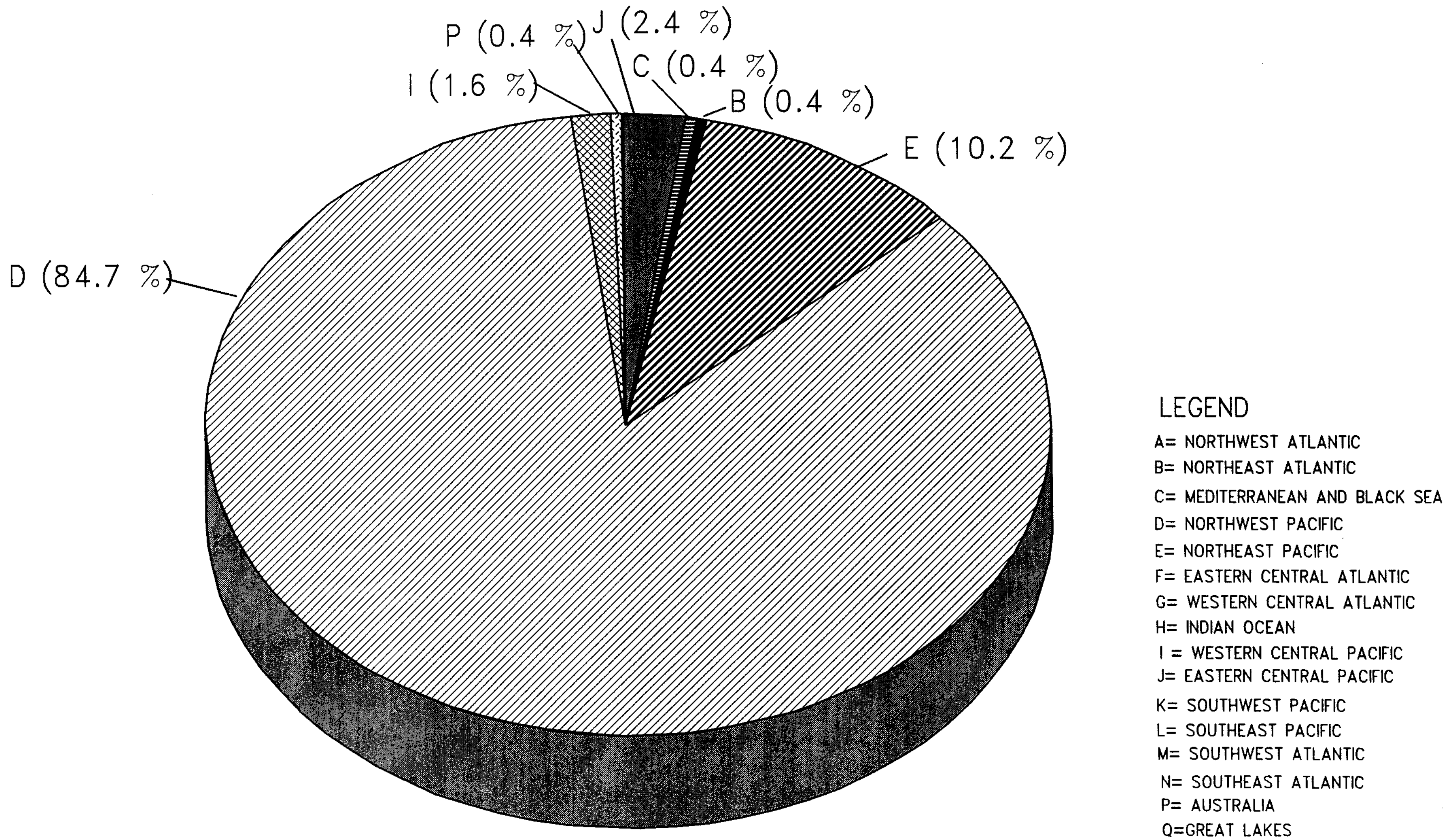


LEGEND

A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS–PORTLAND



LPOC by FAO Region for Ships in Ballast From Foreign Ports

Tacoma, WA

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHWEST PACIFIC	191	60.44
NORTHEAST PACIFIC	121	38.29
SOUTHEAST PACIFIC	1	0.32
WESTERN CENTRAL ATLANTIC	1	0.32
NORTHEAST ATLANTIC	1	0.32
EASTERN CENTRAL PACIFIC	1	0.32
TOTAL	316	100

Seattle, WA

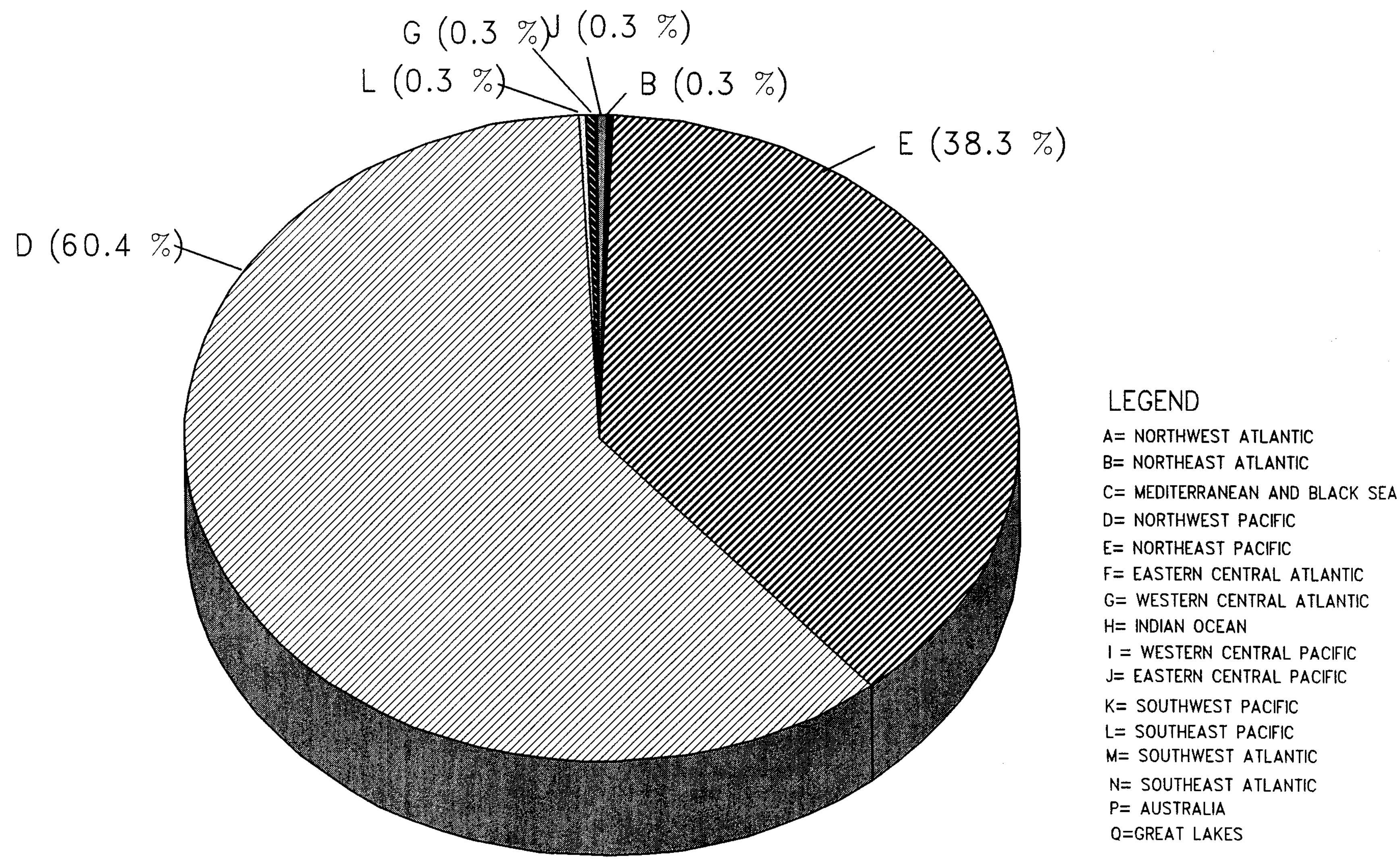
FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHEAST PACIFIC	126	58.88
NORTHWEST PACIFIC	76	35.51
WESTERN CENTRAL PACIFIC	4	1.87
NORTHEAST ATLANTIC	3	1.40
INDIAN OCEAN	2	0.93
WESTERN CENTRAL ATLANTIC	1	0.47
SOUTHEAST PACIFIC	1	0.47
SOUTHWEST PACIFIC	1	0.47
TOTAL	214	100

Anchorage, AK

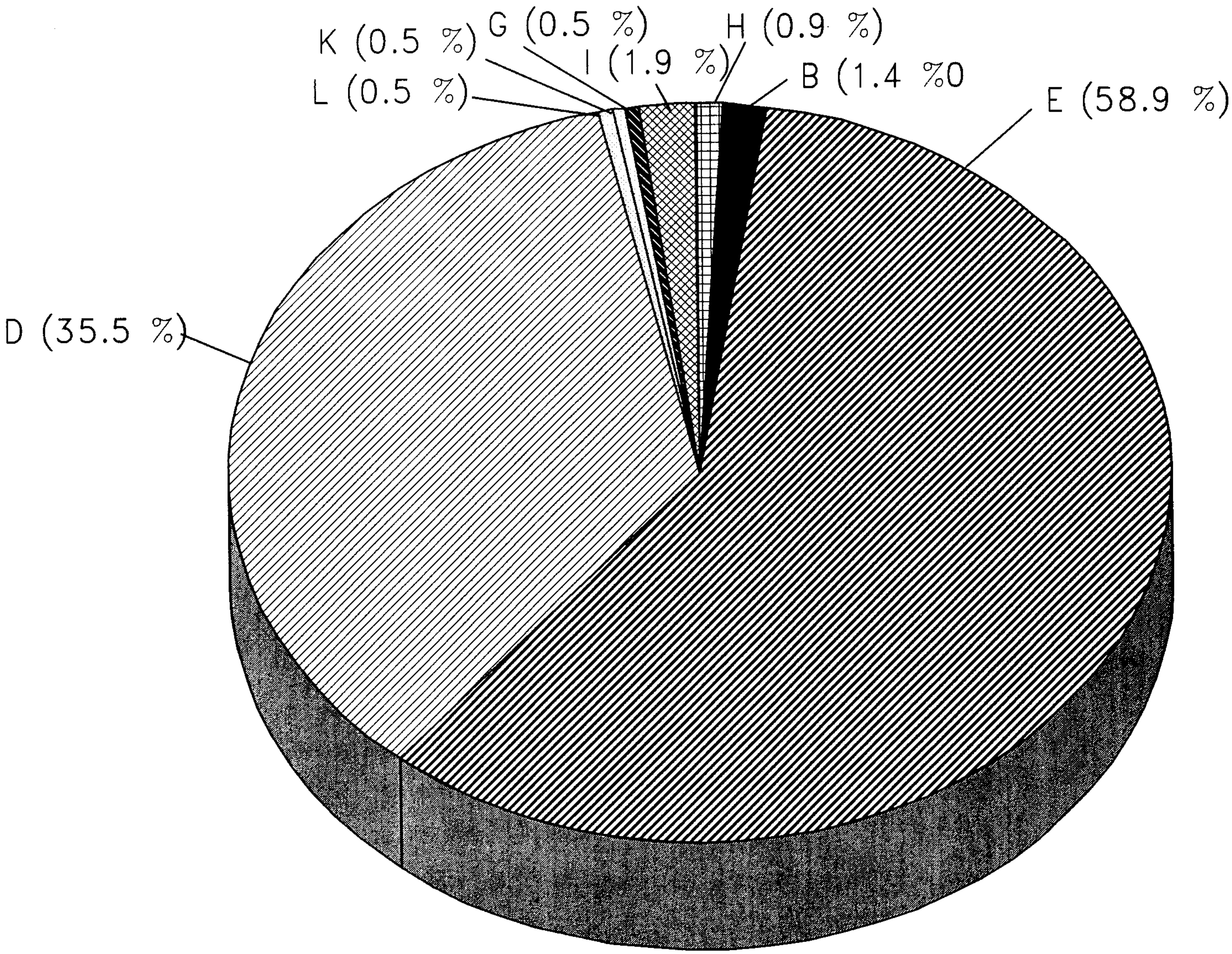
FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHWEST PACIFIC	284	93.73
NORTHEAST PACIFIC	12	3.96
WESTERN CENTRAL PACIFIC	4	1.32
EASTERN CENTRAL PACIFIC	2	0.66
NORTHEAST ATLANTIC	1	0.33
TOTAL	303	100

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS–TACOMA



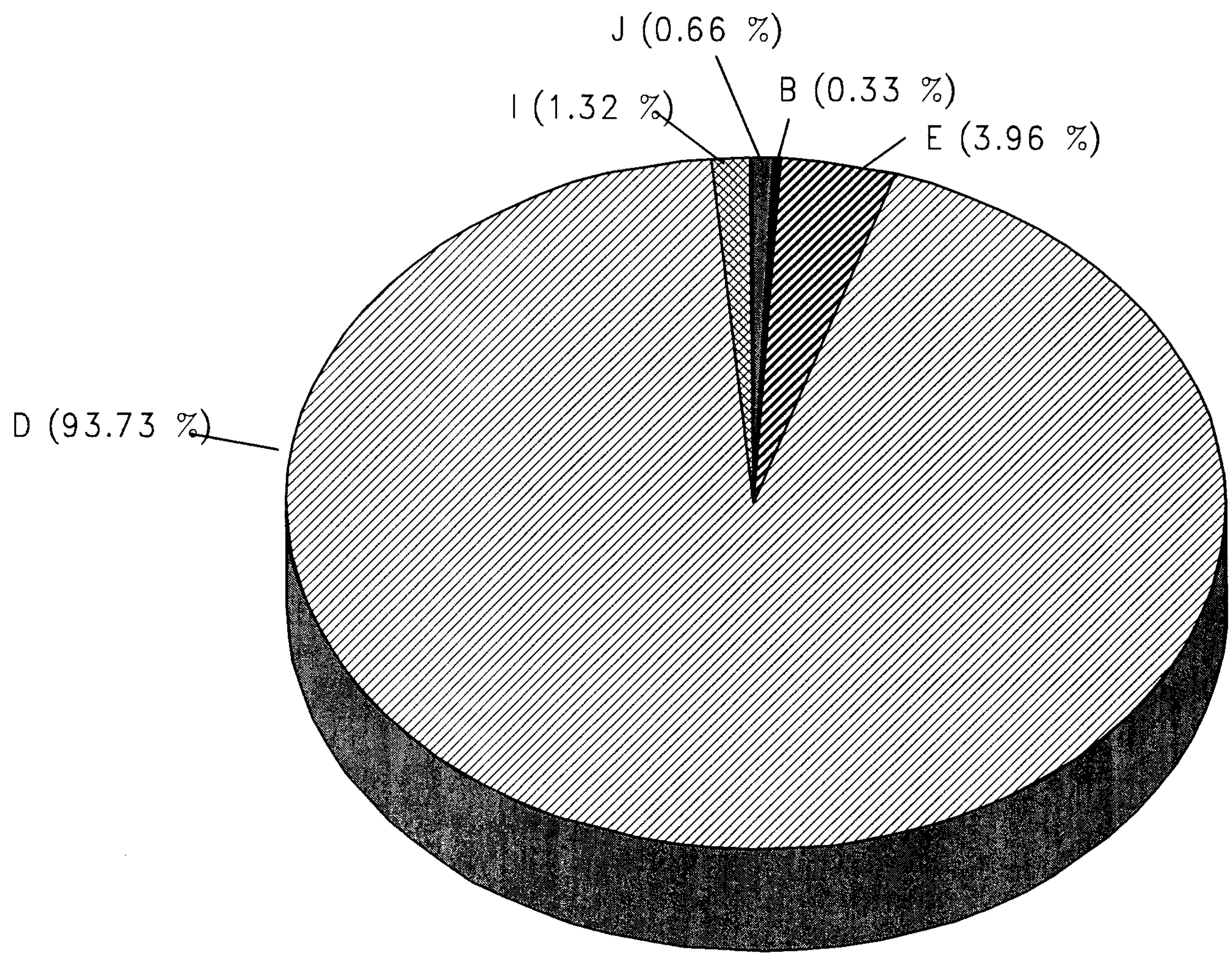
LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS–SEATTLE



LEGEND
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS—ANCHORAGE



LEGEND

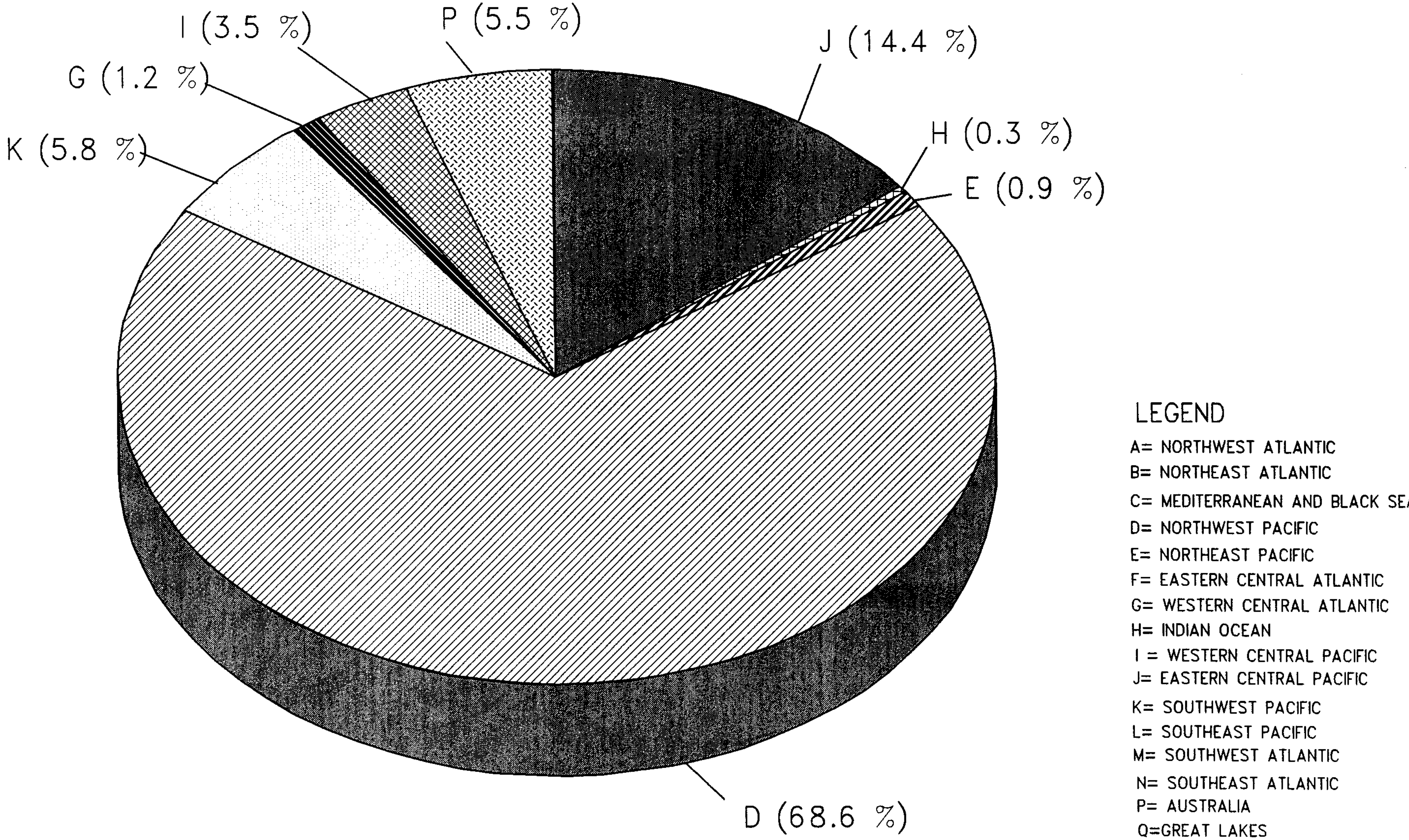
A= NORTHWEST ATLANTIC
B= NORTHEAST ATLANTIC
C= MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
F= EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
I = WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA
Q=GREAT LAKES

LPOC by FAO Region for Ships in Ballast From Foreign Ports

Honolulu, HI

FAO REGION	FREQ	% OF TOTAL FOREIGN SHIPS IN BALLAST
NORTHWEST PACIFIC	238	68.59
EASTERN CENTRAL PACIFIC	50	14.41
SOUTHWEST PACIFIC	39	11.24
WESTERN CENTRAL PACIFIC	12	3.46
WESTERN CENTRAL ATLANTIC	4	1.15
NORTHEAST PACIFIC	3	0.86
INDIAN OCEAN	1	0.29
TOTAL	347	100

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS—HONOLULU

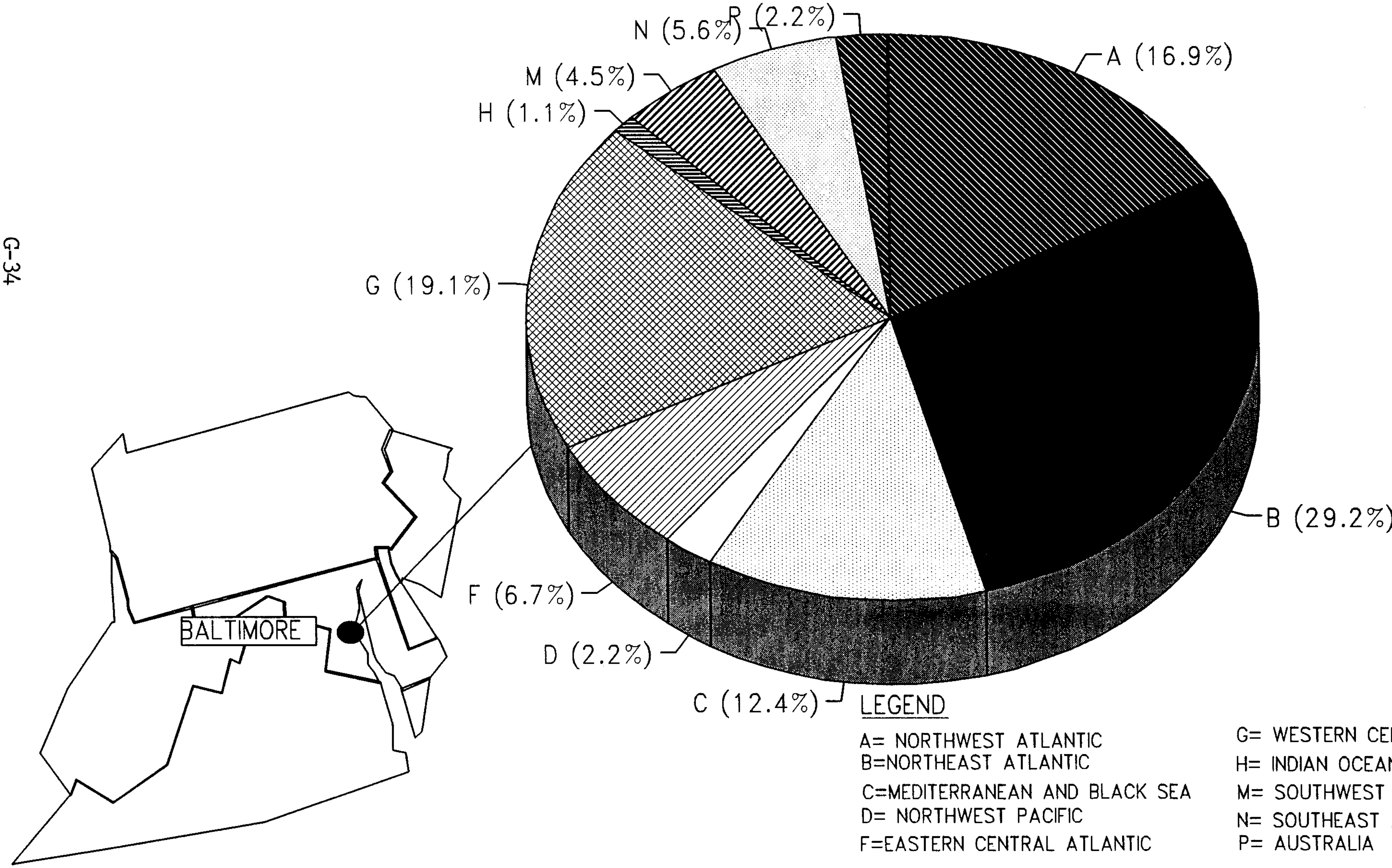


LAST PORT OF CALL BY FAO REGION-- BALTIMORE, MD

STATUS	FAO REGION	FREQ	% OF TOTAL SAMPLE
FOREIGN IN BALLAST	EASTERN CENTRAL ATLANTIC	3	1.04
	MEDITERRANEAN AND BLACK SEA	7	2.43
	NORTHEAST ATLANTIC	18	6.25
	NORTHWEST ATLANTIC	2	0.69
	WESTERN CENTRAL ATLANTIC	3	1.04
FOREIGN IN CARGO	EASTERN CENTRAL ATLANTIC	3	1.04
	INDIAN OCEAN	1	0.35
	MEDITERRANEAN AND BLACK SEA	4	1.39
	NORTHEAST ATLANTIC	8	2.78
	NORTHWEST ATLANTIC	13	4.51
	NORTHWEST PACIFIC	2	0.69
	SOUTHEAST ATLANTIC	5	1.74
	SOUTHWEST ATLANTIC	4	1.39
	WESTERN CENTRAL ATLANTIC	14	4.86
	AUSTRALIA	2	0.69
DOMESTIC IN BALLAST	NORTHWEST ATLANTIC	9	3.13
	WESTERN CENTRAL ATLANTIC	9	3.13
DOMESTIC IN CARGO	NORTHWEST ATLANTIC	110	38.19
	WESTERN CENTRAL ATLANTIC	70	24.31
	DETROIT	1	0.35
	TOTAL SAMPLE	288	100

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS-- BALTIMORE, MD



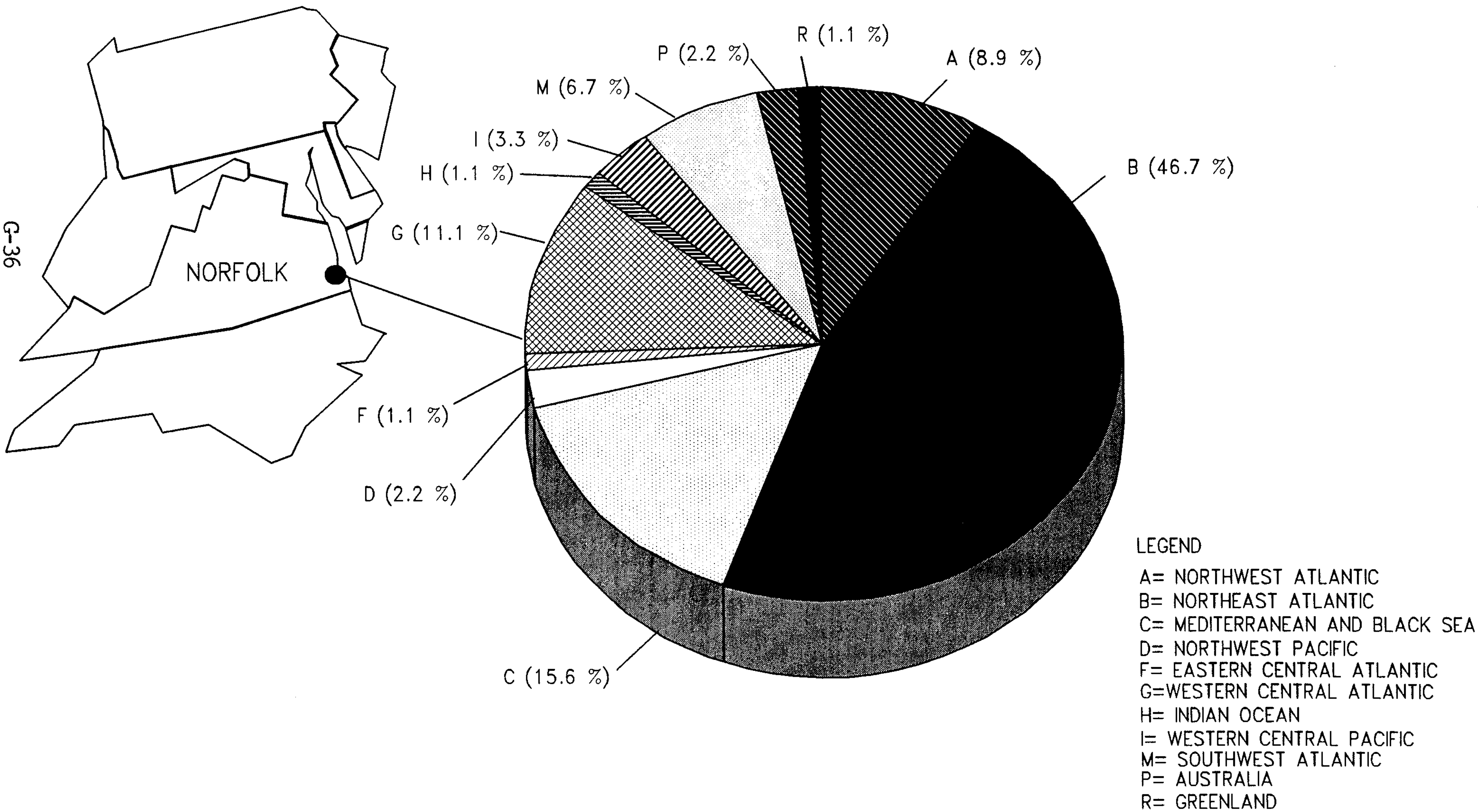
LEGEND

A= NORTHWEST ATLANTIC
B=NORTHEAST ATLANTIC
C=MEDITERRANEAN AND BLACK SEA
D= NORTHWEST PACIFIC
F=EASTERN CENTRAL ATLANTIC
G= WESTERN CENTRAL ATLANTIC
H= INDIAN OCEAN
M= SOUTHWEST ATLANTIC
N= SOUTHEAST ATLANTIC
P= AUSTRALIA

LAST PORT OF CALL BY FAO REGION-- NORFOLK, VA

STATUS	FAO REGION	FREQ	% OF TOTAL SAMPLE
FOREIGN IN BALLAST	EASTERN CENTRAL ATLANTIC	1	0.35
	MEDITERRANEAN AND BLACK SEA	10	3.47
	NORTHEAST ATLANTIC	31	10.76
	WESTERN CENTRAL ATLANTIC	1	0.35
FOREIGN IN CARGO	INDIAN OCEAN	1	0.35
	MEDITERRANEAN AND BLACK SEA	4	1.39
	NORTHEAST ATLANTIC	11	3.82
	NORTHWEST ATLANTIC	8	2.78
	NORTHWEST PACIFIC	2	0.69
	SOUTHWEST ATLANTIC	6	2.08
	WESTERN CENTRAL ATLANTIC	9	3.13
	WESTERN CENTRAL PACIFIC	3	1.04
	AUSTRALIA	2	0.69
	GREENLAND	1	0.35
DOMESTIC IN BALLAST	NORTHWEST ATLANTIC	11	3.82
	WESTERN CENTRAL ATLANTIC	3	1.04
DOMESTIC IN CARGO	NORTHWEST ATLANTIC	125	43.40
	WESTERN CENTRAL ATLANTIC	59	20.49
	TOTAL SAMPLE	288	100

LAST PORT OF CALL BY FAO REGION
FOR SHIPS FROM FOREIGN PORTS-- NORFOLK, VA

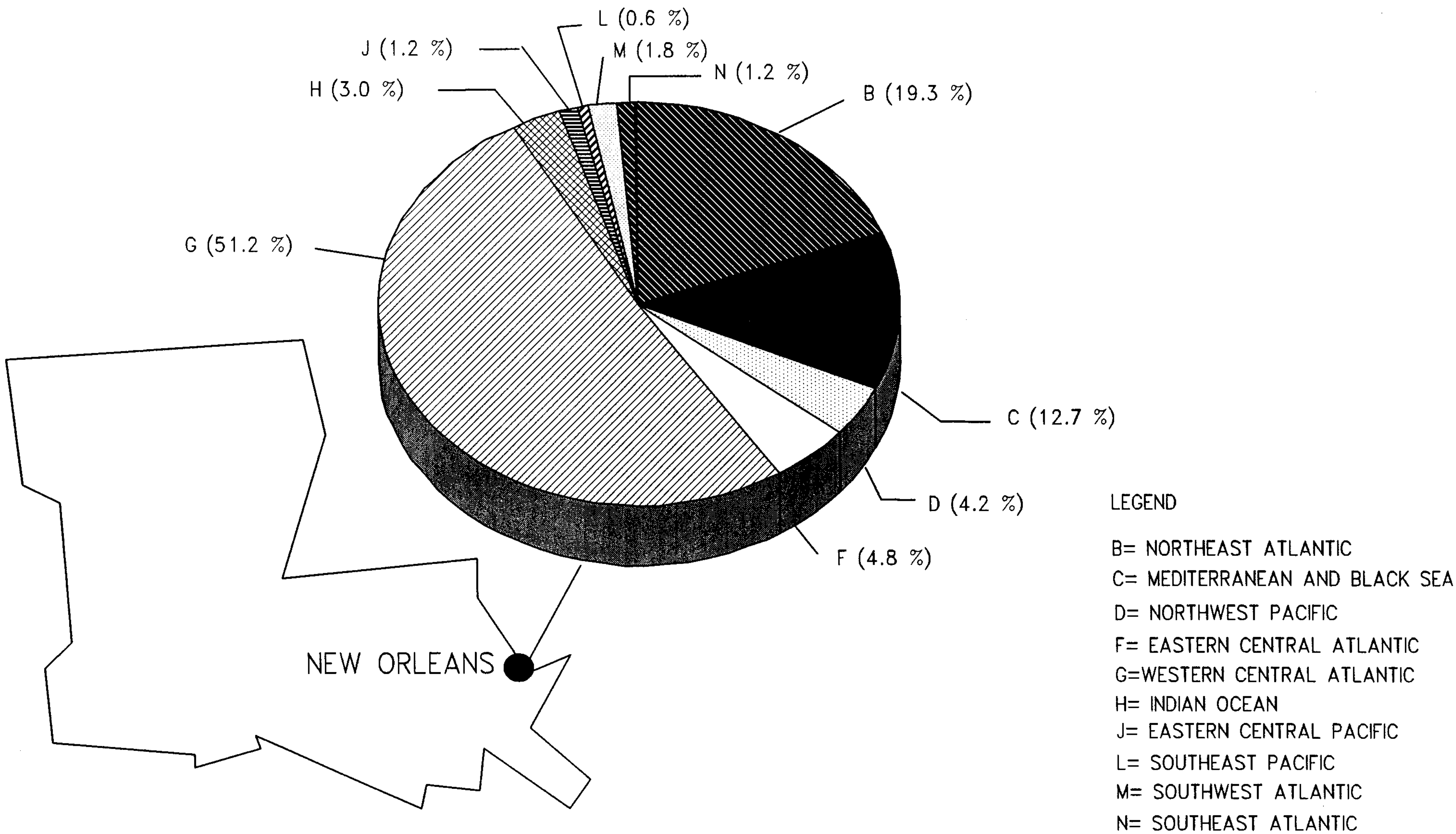


LAST PORT OF CALL BY FAO REGION-- NEW ORLEANS, LA

STATUS	FAO REGION	FREQ	% OF TOTAL SAMPLE
FOREIGN IN BALLAST	EASTERN CENTRAL ATLANTIC	6	2.08
	EASTERN CENTRAL PACIFIC	1	0.35
	INDIAN OCEAN	4	1.39
	MEDITERRANEAN AND BLACK SEA	15	5.21
	NORTHEAST ATLANTIC	24	8.33
	NORTHWEST PACIFIC	5	1.74
	WESTERN CENTRAL ATLANTIC	45	15.63
FOREIGN IN CARGO	EASTERN CENTRAL ATLANTIC	2	0.69
	EASTERN CENTRAL PACIFIC	1	0.35
	INDIAN OCEAN	1	0.35
	MEDITERRANEAN AND BLACK SEA	6	2.08
	NORTHEAST ATLANTIC	8	2.78
	NORTHWEST PACIFIC	2	0.69
	SOUTHEAST ATLANTIC	2	0.69
	SOUTHEAST PACIFIC	1	0.35
	SOUTHWEST ATLANTIC	3	1.04
	WESTERN CENTRAL ATLANTIC	40	13.89
DOMESTIC IN BALLAST	NORTHWEST ATLANTIC	5	1.74
	WESTERN CENTRAL ATLANTIC	26	9.03
DOMESTIC IN CARGO	EASTERN CENTRAL PACIFIC	3	1.04
	NORTHWEST ATLANTIC	6	2.08
	WESTERN CENTRAL ATLANTIC	82	28.47
	TOTAL SAMPLE	288	100

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS-- NEW ORLEANS, LA

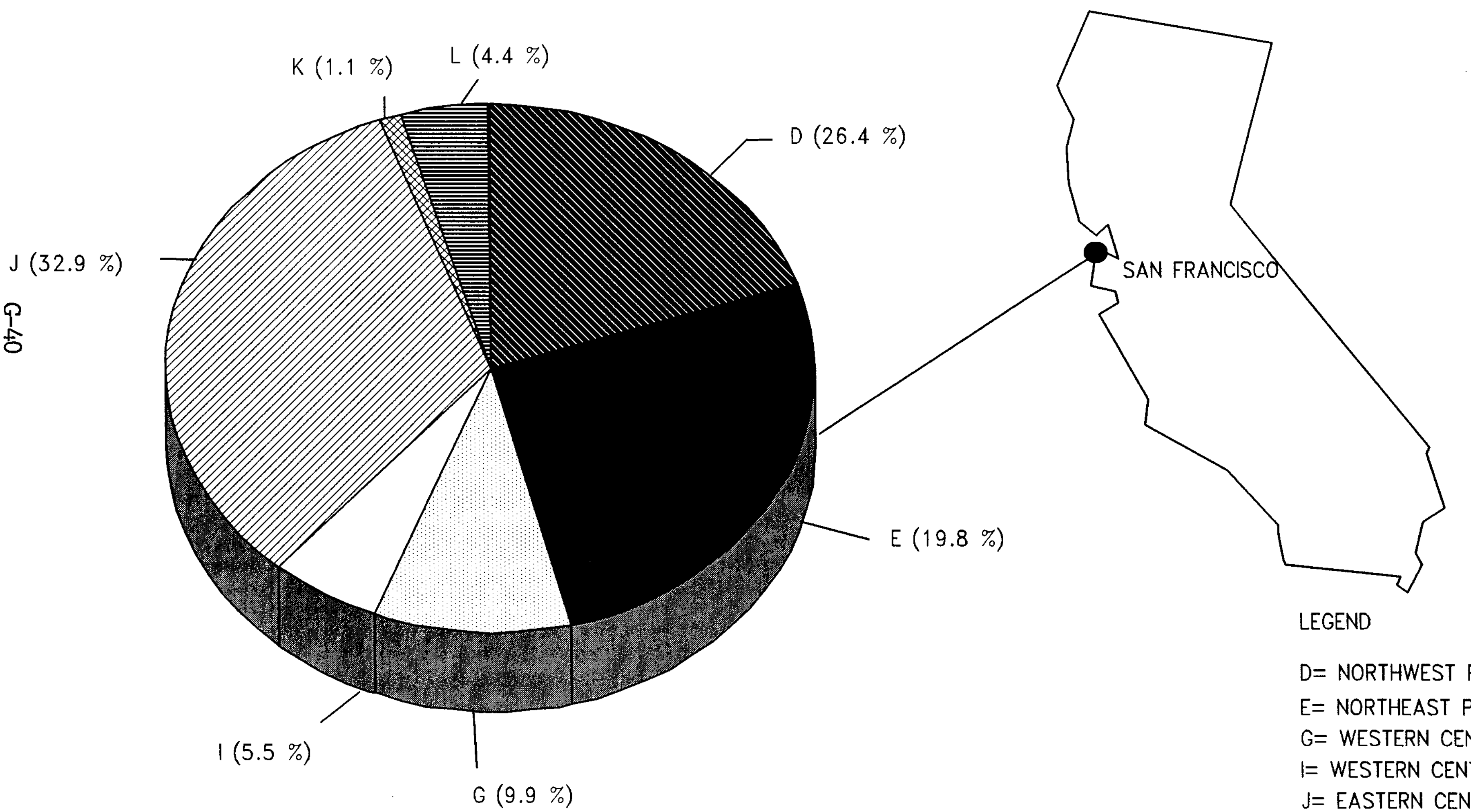


LAST PORT OF CALL BY FAO REGION-- SAN FRANCISCO, CA

STATUS	FAO REGION	FREQ	% OF TOTAL SAMPLE
FOREIGN IN BALLAST	NORTHEAST PACIFIC	13	4.51
	NORTHWEST PACIFIC	5	1.74
FOREIGN IN CARGO	EASTERN CENTRAL PACIFIC	30	10.42
	NORTHEAST PACIFIC	11	3.82
	NORTHWEST PACIFIC	13	4.51
	SOUTHEAST PACIFIC	4	1.39
	SOUTHWEST PACIFIC	1	0.35
	WESTERN CENTRAL ATLANTIC	9	3.13
	WESTERN CENTRAL PACIFIC	5	1.74
DOMESTIC IN BALLAST	EASTERN CENTRAL PACIFIC	22	7.64
	NORTHEAST PACIFIC	2	0.69
DOMESTIC IN CARGO	EASTERN CENTRAL PACIFIC	133	46.18
	NORTHEAST PACIFIC	38	13.19
	WESTERN CENTRAL ATLANTIC	2	0.69
	TOTAL SAMPLE	288	100

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS-- SAN FRANCISCO, CA



LEGEND

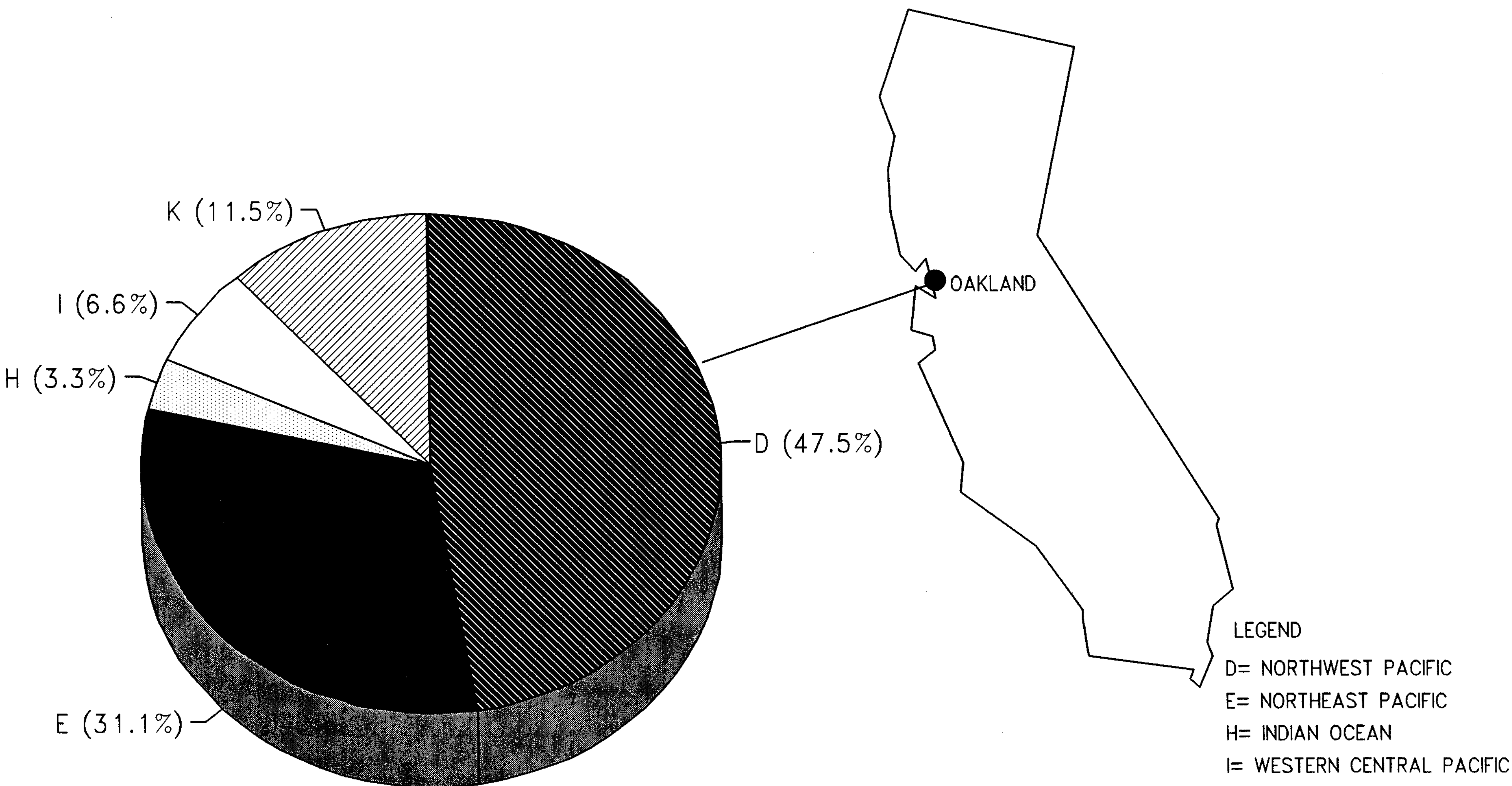
D= NORTHWEST PACIFIC
E= NORTHEAST PACIFIC
G= WESTERN CENTRAL ATLANTIC
I= WESTERN CENTRAL PACIFIC
J= EASTERN CENTRAL PACIFIC
K= SOUTHWEST PACIFIC
L= SOUTHEAST PACIFIC

LAST PORT OF CALL BY FAO REGION-- OAKLAND, CA

STATUS	FAO REGION	FREQ	% OF TOTAL SAMPLE
FOREIGN IN BALLAST	NORTHEAST PACIFIC	1	0.35
	NORTHWEST PACIFIC	4	1.39
FOREIGN IN CARGO	INDIAN OCEAN	2	0.69
	NORTHEAST PACIFIC	18	6.25
	NORTHWEST PACIFIC	25	8.68
	SOUTHWEST PACIFIC	7	2.43
	WESTERN CENTRAL PACIFIC	4	1.39
DOMESTIC IN BALLAST	EASTERN CENTRAL PACIFIC	1	0.35
DOMESTIC IN CARGO	EASTERN CENTRAL PACIFIC	197	68.40
	NORTHEAST PACIFIC	29	10.07
	TOTAL SAMPLE	288	100

LAST PORT OF CALL BY FAO REGION

FOR SHIPS FROM FOREIGN PORTS-- OAKLAND, CA



APPENDIX H

NABISS PORTS:

Last Ports of Call

by Individual Country/Regions

for Foreign Ships in Ballast

NABISS PORTS: Last Ports of Call by Individual Country/Regions for Foreign Ships in Ballast

LPOC designations reflect Census Bureau usage of geographic names for the time (1991) that the data were collected

BOSTON, MA

LPOC	FREQ	NAME
1224	12	Canada, Atlantic Region including St. Pierre and Miquelon
4230	4	Belgium & Luxembourg
4701	3	Spain, Atlantic Region ports North of Portugal
4611	3	USSR, Arctic Region
2320	3	Bermuda
4120	2	United Kingdom
9990	2	High Seas
3070	1	Venezuela
4703	1	Spain, Mediterranean Region
2360	1	Bahamas
2770	1	Aruba & Netherlands Antilles
4720	1	Gibraltar
4750	1	Italy
7291	1	Egypt, Mediterranean Region
14	36	TOTAL

NEW YORK, NY

LPOC	FREQ	NAME
2320	80	Bermuda
4120	20	United Kingdom
1224	13	Canada, Atlantic Region including St. Pierre and Miquelon
2770	9	Aruba & Netherlands Antilles
2360	8	Bahamas
4720	7	Gibraltar
4282	6	Federal Republic of Germany, Atlantic Region
4230	4	Belgium & Luxembourg
4703	4	Spain, Mediterranean Region
7292	4	Egypt, Red Sea Region
4750	3	Italy
4210	3	Netherlands
4271	3	France, Atlantic Region
4712	3	Azores
4702	3	Spain, Atlantic Region ports South of Portugal
3070	3	Venezuela
2390	2	Cuba
2480	2	Leeward & Windward Islands
5170	2	Saudi Arabia

2012	2	Mexico, Gulf or East Coast Region
4840	2	Greece
4890	2	Turkey
5880	2	Japan
7210	1	Algeria
5081	1	Israel, Mediterranean Region
5570	1	Malaysia
7420	1	Cameroon
5330	1	India
7141	1	Morocco, Atlantic Region
5250	1	Bahrain
2740	1	Trinidad & Tobago
3510	1	Brazil
2470	1	Dominican Republic
1223	1	Montreal, Canada
2231	1	Costa Rica, Caribbean Region
4050	1	Finland
4704	1	Canary Islands
4790	1	Yugoslavia
4701	1	Spain, Atlantic Region ports North of Portugal
4550	1	Poland
4611	1	USSR, Arctic Region
41	205	TOTAL

BALTIMORE, MD

LPOC	FREQ	NAME
4210	23	Netherlands
1224	17	Canada, Atlantic Region including St. Pierre and Miquelon
4120	14	United Kingdom
4230	14	Belgium & Luxembourg
4271	13	France, Atlantic Region
4703	11	Spain, Mediterranean Region
4282	10	Federal Republic of Germany, Atlantic Region
4711	9	Madeira Islands
4750	7	Italy
4090	6	Denmark (Except Greenland)
4720	6	Gibraltar
4840	6	Greece
4702	5	Spain, Atlantic Region ports South of Portugal
4701	5	Spain, Atlantic Region ports North of Portugal
5570	5	Malaysia
2470	4	Dominican Republic

4272	4	France, Mediterranean Region
4704	3	Canary Islands
5081	3	Israel, Mediterranean Region
4550	3	Poland
4190	2	Ireland
1223	2	Montreal, Canada
4613	2	USSR, Black Sea Region
4890	2	Turkey
4850	2	Romania
7141	2	Morocco, Atlantic Region
4910	2	Cyprus
2360	2	Bahamas
3510	2	Brazil
3011	2	Colombia, Caribbean Region
7210	2	Algeria
2012	2	Mexico, Gulf or East Coast Region
4010	1	Sweden
7230	1	Tunisia
5880	1	Japan
5600	1	Indonesia
3070	1	Venezuela
4790	1	Yugoslavia
7291	1	Egypt, Mediterranean Region
2320	1	Bermuda
9990	1	High Seas
4050	1	Finland
2410	1	Jamaica
2251	1	Panama, Caribbean Region
44	204	TOTAL

NORFOLK, VA

LPOC	FREQ	NAME
4210	62	Netherlands
4750	53	Italy
4230	43	Belgium & Luxembourg
4271	35	France, Atlantic Region
4120	31	United Kingdom
4701	27	Spain, Atlantic Region ports North of Portugal
4711	16	Madeira Islands
1224	14	Canada, Atlantic Region including St. Pierre and Miquelon
4282	14	Federal Republic of Germany, Atlantic Region
7210	11	Algeria

4720	9	Gibraltar
4702	8	Spain, Atlantic Region ports South of Portugal
4090	8	Denmark (Except Greenland)
4190	8	Ireland
4890	8	Turkey
2410	5	Jamaica
4703	5	Spain, Mediterranean Region
4704	5	Canary Islands
4840	4	Greece
4613	4	USSR, Black Sea Region
4550	4	Poland
4030	4	Norway
3070	4	Venezuela
4010	4	Sweden
7291	3	Egypt, Mediterranean Region
7141	3	Morocco, Atlantic Region
2012	3	Mexico, Gulf or East Coast Region
4272	3	France, Mediterranean Region
4850	2	Romania
2320	2	Bermuda
2480	2	Leeward & Windward Islands
2470	2	Dominican Republic
7910	2	Republic of South Africa
7250	2	Libya
2252	2	Panama, West Coast Region
4870	1	Bulgaria
2740	1	Trinidad & Tobago
7292	1	Egypt, Red Sea Region
5170	1	Saudi Arabia
4612	1	USSR, Baltic Region
2390	1	Cuba
2110	1	El Salvador
4050	1	Finland
3011	1	Colombia, Caribbean Region
4790	1	Yugoslavia
2770	1	Aruba & Netherlands Antilles
2360	1	Bahamas
2830	1	French West Indies
48	425	TOTAL

CHARLESTON, SC

LPOC	FREQ	NAME
4210	9	Netherlands
4120	4	United Kingdom
4282	4	Federal Republic of Germany, Atlantic Region
2360	3	Bahamas
4840	2	Greece
1224	2	Canada, Atlantic Region including St. Pierre and Miquelon
2012	2	Mexico, Gulf or East Coast Region
7141	2	Morocco, Atlantic Region
5170	2	Saudi Arabia
4890	2	Turkey
2320	2	Bermuda
2470	1	Dominican Republic
4790	1	Yugoslavia
4711	1	Madeira Islands
2450	1	Haiti
7210	1	Algeria
5380	1	Bangladesh
2410	1	Jamaica
4703	1	Spain, Mediterranean Region
4090	1	Denmark (Except Greenland)
3070	1	Venezuela
3310	1	Ecuador
4000	1	Iceland
1223	1	Montreal, Canada
4702	1	Spain, Atlantic Region ports South of Portugal
3011	1	Colombia, Caribbean Region
4230	1	Belgium & Luxembourg
27	50	TOTAL

SAVANNAH, GA

LPOC	FREQ	NAME
4210	10	Netherlands
5880	9	Japan
4750	7	Italy
4282	5	Federal Republic of Germany, Atlantic Region
4120	5	United Kingdom
4230	4	Belgium & Luxembourg
2360	4	Bahamas
2450	4	Haiti
2410	3	Jamaica

2390	3	Cuba
2151	3	Honduras, Caribbean Region
3070	3	Venezuela
4271	3	France, Atlantic Region
1224	3	Canada, Atlantic Region including St. Pierre and Miquelon
2470	2	Dominican Republic
4702	2	Spain, Atlantic Region ports South of Portugal
2480	2	Leeward & Windward Islands
2430	2	Turks & Caicos Islands
3150	2	Suriname (Netherlands Guiana)
2740	2	Trinidad & Tobago
7141	2	Morocco, Atlantic Region
4281	2	Federal Republic of Germany, Baltic Region
4711	2	Madeira Islands
3011	2	Colombia, Caribbean Region
3310	1	Ecuador
4190	1	Ireland
4720	1	Gibraltar
4703	1	Spain, Mediterranean Region
4704	1	Canary Islands
4701	1	Spain, Atlantic Region ports North of Portugal
7530	1	Nigeria (incl. former Northern British Cameroons)
4840	1	Greece
7210	1	Algeria
5830	1	Republic of China (Taiwan)
2012	1	Mexico, Gulf or East Coast Region
35	97	TOTAL

MIAMI, FL

LPOC	FREQ	NAME
2360	1636	Bahamas
2450	468	Haiti
9990	199	High Seas
2012	125	Mexico, Gulf or East Coast Region
2410	78	Jamaica
2770	56	Aruba & Netherlands Antilles
2470	12	Dominican Republic
2440	10	Cayman Islands
2830	7	French West Indies
2390	6	Cuba
2430	6	Turks & Caicos Islands
2251	6	Panama, Caribbean Region

3011	5	Colombia, Caribbean Region
2480	5	Leeward & Windward Islands
1224	4	Canada, Atlantic Region including St. Pierre and Miquelon
2740	3	Trinidad & Tobago
2720	3	Barbados
2191	3	Nicaragua, Caribbean Region
2151	3	Honduras, Caribbean Region
2080	3	Belize
2051	3	Guatemala, Caribbean Region
3370	2	Chile
4230	2	Belgium & Luxembourg
4703	2	Spain, Mediterranean Region
4704	1	Canary Islands
2252	1	Panama, West Coast Region
4702	1	Spain, Atlantic Region ports South of Portugal
4750	1	Italy
2320	1	Bermuda
5650	1	Philippines
4840	1	Greece
4282	1	Federal Republic of Germany, Atlantic Region
3330	1	Peru
3310	1	Ecuador
3150	1	Suriname (Netherlands Guiana)
3070	1	Venezuela
2231	1	Costa Rica, Caribbean Region
4120	1	United Kingdom
3510	1	Brazil
39	2662	TOTAL

TAMPA, FL

LPOC	FREQ	NAME
2012	31	Mexico, Gulf or East Coast Region
4210	27	Netherlands
2440	20	Cayman Islands
2450	17	Haiti
3011	16	Colombia, Caribbean Region
4120	15	United Kingdom
2470	14	Dominican Republic
4282	14	Federal Republic of Germany, Atlantic Region
2151	12	Honduras, Caribbean Region
2390	12	Cuba
2410	11	Jamaica

4230	11	Belgium & Luxembourg
5880	11	Japan
7210	10	Algeria
3070	8	Venezuela
4750	8	Italy
4840	8	Greece
2252	8	Panama, West Coast Region
4271	7	France, Atlantic Region
4720	7	Gibraltar
9990	6	High Seas
7141	5	Morocco, Atlantic Region
2011	5	Mexico West Coast Region
5800	4	Republic of Korea
4190	4	Ireland
5701	4	People's Republic of China, Northern Area
4550	4	Poland
4703	4	Spain, Mediterranean Region
4704	4	Canary Islands
1224	4	Canada, Atlantic Region including St. Pierre and Miquelon
3510	4	Brazil
4850	4	Romania
2740	4	Trinidad & Tobago
7291	4	Egypt, Mediterranean Region
4711	4	Madeira Islands
4613	3	USSR, Black Sea Region
2251	3	Panama, Caribbean Region
3330	3	Peru
2080	3	Belize
4890	3	Turkey
4702	2	Spain, Atlantic Region ports South of Portugal
5830	2	Republic of China (Taiwan)
4701	2	Spain, Atlantic Region ports North of Portugal
7480	2	Ivory Coast
2480	2	Leeward & Windward Islands
2770	2	Aruba & Netherlands Antilles
7910	2	Republic of South Africa
2051	2	Guatemala, Caribbean Region
2110	2	El Salvador
9993	2	Gulf of Mexico
7292	2	Egypt, Red Sea Region
4611	2	USSR, Arctic Region
3310	2	Ecuador

3120	2	Guyana
7420	1	Cameroon
7142	1	Morocco, Mediterranean Region
7230	1	Tunisia
5820	1	Hong Kong
5790	1	North Korea
2830	1	French West Indies
4010	1	Sweden
4030	1	Norway
2430	1	Turks & Caicos Islands
2231	1	Costa Rica, Caribbean Region
2232	1	Costa Rica, West Coast Region
2360	1	Bahamas
4272	1	France, Mediterranean Region
4870	1	Bulgaria
4910	1	Cyprus
5170	1	Saudi Arabia
4730	1	Malta & Gozo
4281	1	Federal Republic of Germany, Baltic Region
4612	1	USSR, Baltic Region
4712	1	Azores
74	394	TOTAL

NEW ORLEANS, LA

LPOC	FREQ	NAME
2012	152	Mexico, Gulf or East Coast Region
4210	114	Netherlands
2410	61	Jamaica
4230	49	Belgium & Luxembourg
4750	48	Italy
3070	47	Venezuela
4271	41	France, Atlantic Region
4613	39	USSR, Black Sea Region
2470	39	Dominican Republic
4120	39	United Kingdom
4703	32	Spain, Mediterranean Region
4282	32	Federal Republic of Germany, Atlantic Region
5880	26	Japan
4701	23	Spain, Atlantic Region ports North of Portugal
4840	23	Greece
7210	22	Algeria
4702	22	Spain, Atlantic Region ports South of Portugal

4612	20	USSR, Baltic Region
4711	20	Madeira Islands
2390	20	Cuba
3011	19	Colombia, Caribbean Region
4890	18	Turkey
2151	17	Honduras, Caribbean Region
1224	15	Canada, Atlantic Region including St. Pierre and Miquelon
7291	14	Egypt, Mediterranean Region
2051	12	Guatemala, Caribbean Region
4272	12	France, Mediterranean Region
4720	12	Gibraltar
2252	11	Panama, West Coast Region
4090	11	Denmark (Except Greenland)
9990	10	High Seas
4550	10	Poland
7292	10	Egypt, Red Sea Region
4850	9	Romania
5701	9	People's Republic of China, Northern Area
7141	8	Morocco, Atlantic Region
4190	8	Ireland
2011	8	Mexico West Coast Region
2450	8	Haiti
3120	7	Guyana
5800	7	Republic of Korea
2770	7	Aruba & Netherlands Antilles
4010	7	Sweden
2740	6	Trinidad & Tobago
7230	6	Tunisia
4790	6	Yugoslavia
4704	6	Canary Islands
5081	6	Israel, Mediterranean Region
3330	6	Peru
9993	5	Gulf of Mexico
3310	5	Ecuador
2052	5	Guatemala, West Coast Region
2232	5	Costa Rica, West Coast Region
5830	5	Republic of China (Taiwan)
3012	5	Columbia, West Coast Region
2110	5	El Salvador
2231	5	Costa Rica, Caribbean Region
4030	4	Norway
4614	4	USSR, Eastern Region

2360	4	Bahamas
2830	3	French West Indies
3510	3	Brazil
1223	3	Montreal, Canada
2430	3	Turks & Caicos Islands
2251	3	Panama, Caribbean Region
2720	3	Barbados
7490	2	Ghana
2080	2	Belize
5590	2	Singapore
2480	2	Leeward & Windward Islands
4730	2	Malta & Gozo
4611	2	USSR, Arctic Region
4050	2	Finland
7910	2	Republic of South Africa
4870	2	Bulgaria
2192	2	Nicaragua, West Coast Region
7440	1	Senegal
7530	1	Nigeria (incl. former Northern British Cameroons)
7740	1	Ethiopia (incl. Eritrea)
7650	1	Liberia
7550	1	Gabon
4281	1	Federal Republic of Germany, Baltic Region
5020	1	Syria (including Latakia)
3150	1	Suriname (Netherlands Guiana)
1221	1	Canada, Pacific Region
2440	1	Cayman Islands
5170	1	Saudi Arabia
5420	1	Sri Lanka
5820	1	Hong Kong
5380	1	Bangladesh
5230	1	Oman
5350	1	Pakistan
92	1260	TOTAL

HOUSTON, TX

LPOC	FREQ	NAME
2012	163	Mexico, Gulf or East Coast Region
3011	43	Colombia, Caribbean Region
3070	43	Venezuela
2410	25	Jamaica
2051	24	Guatemala, Caribbean Region

2390	23	Cuba
2251	22	Panama, Caribbean Region
2450	20	Haiti
2470	18	Dominican Republic
4210	17	Netherlands
7210	14	Algeria
4750	13	Italy
2252	12	Panama, West Coast Region
4230	12	Belgium & Luxembourg
2231	11	Costa Rica, Caribbean Region
3310	11	Ecuador
2360	10	Bahamas
2770	8	Aruba & Netherlands Antilles
4720	8	Gibraltar
2011	8	Mexico West Coast Region
3330	8	Peru
4271	7	France, Atlantic Region
3370	7	Chile
4272	7	France, Mediterranean Region
2151	7	Honduras, Caribbean Region
2110	7	El Salvador
4612	7	USSR, Baltic Region
4701	6	Spain, Atlantic Region ports North of Portugal
1224	6	Canada, Atlantic Region including St. Pierre and Miquelon
4282	5	Federal Republic of Germany, Atlantic Region
4120	5	United Kingdom
4703	5	Spain, Mediterranean Region
5081	5	Israel, Mediterranean Region
9993	5	Gulf of Mexico
3510	5	Brazil
2080	5	Belize
5830	4	Republic of China (Taiwan)
7141	4	Morocco, Atlantic Region
5800	4	Republic of Korea
4712	4	Azores
4840	4	Greece
3012	4	Columbia, West Coast Region
7292	4	Egypt, Red Sea Region
2740	4	Trinidad & Tobago
5170	3	Saudi Arabia
7910	3	Republic of South Africa
2232	3	Costa Rica, West Coast Region

4702	3	Spain, Atlantic Region ports South of Portugal
7291	3	Egypt, Mediterranean Region
4890	2	Turkey
4850	2	Romania
7230	2	Tunisia
2052	2	Guatemala, West Coast Region
5701	2	People's Republic of China, Northern Area
4910	2	Cyprus
7440	2	Senegal
4711	2	Madeira Islands
4613	2	USSR, Black Sea Region
3170	2	French Guiana
4550	2	Poland
4730	2	Malta & Gozo
7320	1	Sudan
3120	1	Guyana
2720	1	Barbados
4090	1	Denmark (Except Greenland)
4030	1	Norway
9990	1	High Seas
1223	1	Montreal, Canada
7470	1	Sierra Leone
7480	1	Ivory Coast
7790	1	Kenya
4611	1	USSR, Arctic Region
4704	1	Canary Islands
5110	1	Jordan
2320	1	Bermuda
2192	1	Nicaragua, West Coast Region
4870	1	Bulgaria
5070	1	Iran
2480	1	Leeward & Windward Islands
5880	1	Japan
6020	1	Australia*
5210	1	Yemen
5650	1	Philippines
2440	1	Cayman Islands
84	696	TOTAL

GALVESTON, TX

LPOC	FREQ	NAME
9990	164	High Seas
2012	34	Mexico, Gulf or East Coast Region
9993	18	Gulf of Mexico
2410	8	Jamaica
2390	5	Cuba
4210	5	Netherlands
4750	5	Italy
3070	4	Venezuela
3310	4	Ecuador
4840	3	Greece
4282	3	Federal Republic of Germany, Atlantic Region
4271	3	France, Atlantic Region
2470	3	Dominican Republic
4701	2	Spain, Atlantic Region ports North of Portugal
4612	2	USSR, Baltic Region
4711	2	Madeira Islands
2011	2	Mexico West Coast Region
2051	2	Guatemala, Caribbean Region
5880	2	Japan
4090	2	Denmark (Except Greenland)
3370	1	Chile
5800	1	Republic of Korea
4850	1	Romania
5701	1	People's Republic of China, Northern Area
7210	1	Algeria
2770	1	Aruba & Netherlands Antilles
3012	1	Columbia, West Coast Region
7620	1	Angola (incl. Cabinda)
7250	1	Libya
7292	1	Egypt, Red Sea Region
4120	1	United Kingdom
4702	1	Spain, Atlantic Region ports South of Portugal
4613	1	USSR, Black Sea Region
2360	1	Bahamas
2720	1	Barbados
2231	1	Costa Rica, Caribbean Region
2151	1	Honduras, Caribbean Region

4730	1	Malta & Gozo
4703	1	Spain, Mediterranean Region
4720	1	Gibraltar
40	293	TOTAL

SAN DIEGO, CA

LPOC	FREQ	NAME
2011	620	Mexico West Coast Region
9990	10	High Seas
2252	7	Panama, West Coast Region
2251	4	Panama, Caribbean Region
1221	3	Canada, Pacific Region
2232	2	Costa Rica, West Coast Region
6410	1	French Pacific Islands
2012	1	Mexico, Gulf or East Coast Region
2052	1	Guatemala, West Coast Region
5880	1	Japan
10	650	TOTAL

LONG BEACH, CA

LPOC	FREQ	NAME
5880	107	Japan
2252	49	Panama, West Coast Region
5800	27	Republic of Korea
2011	9	Mexico West Coast Region
5830	7	Republic of China (Taiwan)
5701	4	People's Republic of China, Northern Area
5820	3	Hong Kong
4614	2	USSR, Eastern Region
1221	2	Canada, Pacific Region
9995	2	South Pacific
9990	1	High Seas
2232	1	Costa Rica, West Coast Region
2051	1	Guatemala, Caribbean Region
2012	1	Mexico, Gulf or East Coast Region
3310	1	Ecuador
4890	1	Turkey
4613	1	USSR, Black Sea Region
4120	1	United Kingdom
18	220	TOTAL

LOS ANGELES, CA

LPOC	FREQ	NAME
2011	373	Mexico West Coast Region
5880	62	Japan
5800	20	Republic of Korea
1221	17	Canada, Great Lakes Region
9990	8	High Seas
5830	6	Republic of China (Taiwan)
6410	5	New Zealand
5701	5	People's Republic of China, Northern Area
2232	4	Costa Rica, West Coast Region
3330	4	Peru
2252	4	Panama, West Coast Region
5650	4	Philippines
9995	3	South Pacific
3070	3	Venezuela
4614	2	USSR, Eastern Region
5820	2	Hong Kong
9994	1	North Pacific
6020	1	Australia*
2251	1	Panama, Caribbean Region
2410	1	Jamaica
2052	1	Guatemala, West Coast Region
2110	1	El Salvador
2440	1	Cayman Islands
4010	1	Sweden
5590	1	Singapore
3310	1	Ecuador
3370	1	Chile
27	533	TOTAL

OAKLAND, CA

LPOC	FREQ	NAME
5880	5	Japan
5800	4	Republic of Korea
5590	2	Singapore
9990	1	High Seas
5830	1	Republic of China (Taiwan)
1221	1	Canada, Pacific Region
6	14	TOTAL

SAN FRANCISCO, CA

LPOC	NO	NAME
1221	28	Canada, Pacific Region
5880	7	Japan
2011	5	Mexico West Coast Region
5830	1	Republic of China (Taiwan)
5800	1	Republic of Korea
2251	1	Panama, Caribbean Region
2252	1	Panama, West Coast Region
7	44	TOTAL

PORTLAND, OR

LPOC	FREQ	NAME
5880	143	Japan
5800	44	Republic of Korea
1221	26	Canada, Pacific Region
5830	17	Republic of China (Taiwan)
5701	6	People's Republic of China, Northern Area
4614	4	USSR, Eastern Region
5490	2	Thailand
2052	2	Guatemala, West Coast Region
2252	2	Panama, West Coast Region
6020	1	Australia*
2110	1	El Salvador
2011	1	Mexico West Coast Region
5820	1	Hong Kong
4120	1	United Kingdom
5081	1	Israel, Mediterranean Region
5590	1	Singapore
5790	1	North Korea
5650	1	Philippines
18	255	TOTAL

TACOMA, WA

LPOC	FREQ	NAME
5880	152	Japan
1221	121	Canada, Pacific Region
5800	22	Republic of Korea
5830	14	Republic of China (Taiwan)
5701	3	People's Republic of China, Northern Area
2251	1	Panama, Caribbean Region
2052	1	Guatemala, West Coast Region

4120	1	United Kingdom
3330	1	Peru
9	316	TOTAL

SEATTLE, WA

LPOC	FREQ	NAME
1221	122	Canada, Pacific Region
5880	51	Japan
5800	13	Republic of Korea
5701	5	People's Republic of China, Northern Area
5830	4	Republic of China (Taiwan)
9990	4	High Seas
5650	2	Philippines
9994	2	North Pacific
4230	2	Belgium & Luxembourg
5590	2	Singapore
6410	1	French Pacific Islands
3370	1	Chile
3070	1	Venezuela
4030	1	Norway
5170	1	Saudi Arabia
5820	1	Hong Kong
5200	1	United Arab Emirates
17	214	TOTAL

ANCHORAGE, AK

LPOC	FREQ	NAME
5880	213	Japan
5800	59	Republic of Korea
1221	6	Canada, Pacific Region
9990	6	High Seas
4614	5	USSR, Eastern Region
5701	2	People's Republic of China, Northern Area
5830	2	Republic of China (Taiwan)
4611	2	USSR, Arctic Region
5590	2	Singapore
2011	2	Mexico West Coast Region
4210	1	Netherlands
5650	1	Philippines
5490	1	Thailand
5820	1	Hong Kong
14	303	TOTAL

HONOLULU, HI

LPOC	FREQ	NAME
5880	222	Japan
9990	33	High Seas
6220	19	Australia*
6410	13	French Pacific Islands
2252	10	Panama, West Coast Region
2011	7	Mexico West Coast Region
5800	6	Republic of Korea
6810	6	Marshall Islands
5830	5	Republic of China (Taiwan)
5701	4	People's Republic of China, Northern Area
5590	4	Singapore
9995	4	South Pacific
2251	3	Panama, Caribbean Region
9510	3	American Samoa
1221	3	Canada, Pacific Region
9350	1	Guam
5820	1	Hong Kong
5650	1	Philippines
2232	1	Costa Rica, West Coast Region
5350	1	Pakistan
20	347	TOTAL

* Including Tasmania & Macquarie, Norfolk, Cocos & Christmas Is.

Appendix I: NABISS Port Profiles

By Ellen Anderson

General Summary

The following port profiles are presented as information on individual ports. Due to the heterogeneous nature of the materials provided to us by port authorities, it is difficult to use these profiles for port comparison purposes.

There are several methods of assessing the "size" of a port or port system. The spatial extent in square acres/kilometers is one gauge, as is the number of piers (docks) and/or anchorages available for shipping purposes within a fixed area. Another evaluation of size used by many ports is the actual measurements of the vessels which can be accommodated at the port. Size of vessel may be described as tonnage, length times breadth, draft, or even height of superstructure. Thus ports may define their size by their capability of handling the plurality of vessels in the industry.

In addition to the above factors, ports also list their size in terms of tons of cargo imported (commodities landed - some ports may include commodities arriving by truck or plane as well, without separating these from seaborne commodities), tons of cargo exported, and again the *capacity* of the port to handle cargo versus what they actually *do* handle. Finally, ports tend to describe their size in relation to their rate of growth over time for all of the above.

We use number of vessel arrivals from foreign ports as a measure of port size in the current study. These numbers often include not only cargo vessels but also cruise ships, fishing vessels, barges, tugs, and ferries. The largest number of vessels entering a U.S. port from a foreign source occurs at the Port of Miami, with the port systems of Los Angeles/Long Beach and Houston/Galveston following in very close second and third places. The port system of Seattle/Tacoma is fourth, New York/New Jersey fifth, and New Orleans sixth.

In terms of future growth, and therefore increased volumes of ballast water, every U.S. port we surveyed has plans for increased trade in the future. Ports on the U.S. West Coast look to Pacific Rim countries for an "explosion" of trade in the 21st century. Among others, the Ports of San Diego and Miami intend to continue an expansion of their cruise industries to southern warm water regions. U.S. East Coast ports consider that the new European Community will open up a plurality of potential commerce. For instance, the port system of Hampton Roads expects increased European demand for coal imports to significantly increase coal exports during the 1990s. Ports along the U.S. Gulf Coast look to the south for future opportunities in waterborne traffic. Free trade throughout the Americas would enhance U.S. export opportunities in a region where the U.S. presently supplies over 50 percent of all Latin American and Caribbean imports.

Almost all ports also identified developing countries as posing a significant opportunity, as yet not fully tapped, for the U.S. shipping industry. Two examples are Indonesia and Malaysia. As one of the largest exporters of oil and the largest exporter of liquefied natural gas in the world, Indonesia is increasingly linked to the international economy. American exports to Indonesia have risen by 30 percent annually in 1990 and 1991. Such exports include U.S. cotton, which provides the core of Indonesia's several billion dollar textile industry. U.S. supplied pulp

and waste paper are raw material for Indonesia's growing paper industry. And American wood products are highly valuable, since Indonesia is the world's largest producer of plywood. The same principles apply to Malaysia where telecommunications equipment, computer software, oil and gas equipment, chemical equipment, and semiconductor devices are produced. Malaysia is the world's largest exporter of these commodities. Forty-four percent of the electronic components which are imported into Malaysia come from the United States.

The 21st century clearly holds vast potential for expanded port growth and thus greatly increased volumes of shipping traffic -- and, inevitably, more ballast water.

BOSTON

Boston is New England's most important transportation gateway. Since the mid-1970's, the Massachusetts Port Authority (Massport) has conducted a systematic effort to revitalize Boston's public marine terminals. During the last ten years, Massport has put nearly $200 million into the working waterfront and related facilities. Massport has embarked on a major capital construction agenda to expand terminal facilities and to support the Boston Harbor Dredging Project. The latter is a critical need for the Port to be able to continue to accommodate modern shipping. Presently, ships must use ballast practices to adhere to the many requirements of the bridges in the harbor system.

Boston's container terminal development includes Moran Container Terminal in Charlestown, Conley Terminal in South Boston, and the Massachusetts Marine Terminal at the old South Boston Naval Annex. The Moran Terminal is a full service container terminal with a quay length of 335 meters, and an open storage area of 50 acres. Massport invested $1,045,000 towards improving and expanding the facility in 1991. The Conley Terminal handles containers and automobiles. It received $1,523,000 for terminal expansion programs in 1991 from Massport, and in 1992, a five year, $50 million expansion program was begun. The Harbor Gateway Terminal in South Boston is home to the Port's cruise terminal. Harbor Gateway is also utilized for cement and automobiles.

Massport's total cargo tonnage, which declined during most of the 1970s, has grown steadily since 1978 with exports leading the way. Export growth through the Port of Boston continued during 1991, increasing by 5.3 percent to 400,209 tons, a new record. Total general cargo tonnage amounted to 1,041,499 tons. Ninety-two percent was shipped in containers on regularly scheduled direct, barge, and feeder shipping lines. Overall, the Port of Boston handled nearly 18 million tons of cargo worth $6.8 billion, with 2,174 vessels arriving in the port. From 1983 to 1991 foreign cargo totals for the Port of Boston have fluctuated from 16,767,585 in 1983, up to 25,944,092 in 1986, declining to 17,872,665 in 1991.

Major imports for the Port include petroleum products, cement, natural gas, gypsum, and molasses. Principal exports include fish and products, logs and lumber, and metal waste and scrap. Bulk terminals in Boston are privately owned and operated. The major bulk commodity is petroleum. Other bulk commodities include cement, gypsum, salt, scrap metal, and liquid natural gas. The Distrigas facility in Everett, MA regularly receives shipments of liquefied natural gas (LNG) from the National Algerian Petroleum Cooperation. The shipments, delivered by Algerian-flagged LNG tankers, arrive in port every 11 to 20 days.

The character of commercial shipping serving the New England area through Boston Harbor has undergone a facelift, as has all shipping, due to the "container revolution," and the necessary requirement of open acreage for stowage and retrieval of the containers. An older, more established port, such as Boston lacks the available space for such massive change. In addition, the container vessels being placed in service today are increasing in size and capacity. Studies made in cooperation with government agencies envisioned "load center" ports to which such huge ships would be limited. Their cargo would then be directed to "feeder" ports on smaller vessels or barges in a domestic transportation system. Experts predict only two such "load centers" for the East Coast - New York and another at a large southern port. Boston has rapidly become one of the "feeder" ports within this system on the East Coast. One third of all general container cargo is handled by the feeder service from New York or Canada on barges or small

servicing vessels. Cargo needed to supply the New England region still flows through the Port of Boston at the rate of more than one million long tons each year.

Reference Publications:

Lloyd's Ports of the World
NABISS/NP/#9
USCG Port Needs Study - Volume II: Appendices, Part 1/August 1991
Port of Boston 1990-1992 (from Boston Shipping Association, Inc.)

NEW YORK - NEW JERSEY

The Port of New York/New Jersey is situated at the mouth of the Hudson River. There are eight separate bays and channels embracing the terminals and facilities of Manhattan, Long Island, Staten Island, and New Jersey. Total harbor frontage along navigable waters is 1,933 miles. There are over 250 general cargo vessel berths. Major terminals and port areas include Howland Hook Container Terminal, Brooklyn Port Authority Marine Terminal, South Brooklyn Marine Terminal, Red Hook Container Terminal, East River, New York City Passenger Ship Terminal, Hunt's Point, Global Marine Terminal, Port Raritan, Elizabeth Port Authority Marine Terminal, Port Newark, Port Authority Auto Marine Terminal, 23rd Street Terminal, Fishport, and Foreign Trade Zone No. 1 and No. 49. In addition, there are at least 39 petroleum terminals handling various types of oils, petroleum products, and chemicals.

In 1987, the Port of New York handled 154.5 million tons of cargo. Of this, 10.6 million tons consisted of crude oil and 96.1 million tons were petroleum products. Crude oil cargoes reach New York via shuttle tankers which load at Caribbean trans-shipment centers. Leading general cargo imports include alcoholic beverages, bananas, motor vehicles, coffee, vegetables, plastic and rubber materials, lumber, hydrocarbons, and fish. General cargo exports include waste paper, plastic materials, machinery, textile waste, paper, motor vehicles, and steel.

Economic growth, forecast in the 1990s for both the European Community and Latin America, could bode well for the New York-New Jersey bistate region as an intermodal gateway. If the European Community becomes an import/export region for the Far East, shipping cargo from Europe by ocean to the U.S. East Coast (to then be flown to the Far East), would bring increased trade to the Port of New York. Further increases in trade are reported in the *1991-92 PORT GUIDE*, which notes that for the first time in 20 years, cocoa shipments from Central and South America are coming into the Port. In addition, cargo transiting through the Port from the Far East, via the China Ocean Shipping Company, increased from 151,000 tons in 1986 to 418,000 tons in 1990, for an impressive 177 percent rise.

Construction has begun on a major program of rehabilitating and upgrading the existing marine terminals and warehouses in Port Newark, Elizabeth Port Authority Marine Terminal, and Red Hook Container Terminal. The Port Authority is developing the Greenville Industrial Development on 50 acres of the west shore of upper New York Bay in Jersey City.

Reference Publications:

1991-92 Port of New York & New Jersey Guide Elizabeth: PRIDE
Lloyd's Ports of the World
USCG Port Needs Study - Volume II': Appendices, Part 1/August 1991
Port of New York and New Jersey Oceanborne Foreign Trade Handbook 1991, 1992
The Port Authority of NY & NJ - Annual Report for 1990
VIA Port of New York and New Jersey - June, Dec 91; Jan - Sept 92

PHILADELPHIA/DELAWARE BAY

General Information

The Delaware River Port Area, which includes the cities of Philadelphia, Camden, Gloucester, Chester, Marcus Hook, Paulsboro, Wilmington, and Trenton, is known as the Ports of Philadelphia. It is centrally located on the Atlantic seaboard, and is part of the States of Pennsylvania, New Jersey, and Delaware. The Chesapeake and Delaware Canal connects the Delaware River with Chesapeake Bay. Principal imports and exports are fruit, steel, crude petroleum and petroleum products, lumber, plywood, vehicles, cocoa beans, paper, coal, ore, fertilizers, and meat. There are seven refineries and tanker terminal facilities on the Delaware River, and a total of 41 oil berths at Philadelphia.

Philadelphia

The Port of Philadelphia is located on the Delaware and Schuylkill Rivers. Port facilities consist of 52 marine terminal complexes which provide a total of 115 deep-draft berths. Major terminals are the Pasha Auto Terminal (a major import-export automobile process facility), the Penn Terminal (handles general cargo including containerized breakbulk and neobulk), Pier 80 (handling commodities such as rolled paper, pulp, steel, lumber), Pier 82 and Pier 84 (facilities handle steel, containers, fruit, breakbulk, and heavy lift cargoes), Packer Avenue Marine Terminal (containers, Ro-Ro, and bulk cargo), Tioga Marine Terminal (container and bulk cargo - the terminal has added a 100,000 square foot fruit shed to handle the increased imports of Chilean fruit), Girard Point (general cargo, grain pier), Greenwich Point (ore, coal, and fertilizer), Port Richmond (ore, coal, grain, and other bulk commodities), Northern Shipping Terminal (general cargoes including containerized, breakbulk, and Ro-Ro), and a Foreign Trade Zone.

Plans are being developed for a Regional Intermodal Transfer Facility in South Philadelphia on a 106 acre site next to the Packer Avenue Marine Terminal.

Other Ports

Located in the Central Harbor area across from Philadelphia on the Delaware River, Camden serves the Delaware Valley area and particularly the rapidly expanding southern New Jersey region. Waterborne commerce is handled through several facilities in the Camden/Gloucester area. Camden has two terminals providing five berths and can handle all types of general cargo as well as many types of bulk cargoes (small amount of containers handled, but no Ro-Ro facilities).

The Holt Marine Terminal in adjacent Gloucester City has a major expansion program underway. Principal imports and exports for the Camden/Gloucester area include coal, petroleum, coke, pig iron, plywood, bananas, salt, scrap metal, and steel. In 1989, the port handled 2,338,426 tons of cargo.

Located on the Delaware River south of Philadelphia at the Maryland State border, Wilmington is able to handle general, dry bulk, reefer, Ro-Ro, and container cargoes. Principal commodities include gypsum, ore, petrocoke, iron and steel, salt, vehicles, bananas, lumber, aluminum, frozen beef, fresh fruit, and orange juice. Further berth construction and a reefer warehouse expansion are planned.

Reference Publications:

Lloyd's Ports of the World
USCG Port Needs Study - Volume II: Appendices, Part 2/August 1991

BALTIMORE

The Port of Baltimore, located on the Patapsco River in the north section of the Chesapeake Bay, has sea routes via the main ship channel and Chesapeake Bay to the sea, or via the Chesapeake and Delaware Ship Canal to Delaware Bay and the sea.

The Port of Baltimore has 64 general and 18 bulk cargo berths. The largest general cargo handling facility is Dundalk Marine Terminal covering 175 acres with 13 deepwater berths of which seven are used exclusively for container cargo. Dundalk has Ro-Ro platforms as well, and a passenger service building for cruise ships. The North Locust Point Terminal consists of seven general cargo berths, and a grain pier and elevator. Other terminals operated by the Maryland Port Administration include the South Locust Point Terminal, Clinton Street Marine Terminal, and Hawkins Point Terminal. Atlantic Terminals manages a 432 acre automobile import facility, Sea-Land operates a terminal for its European, Mediterranean, and Far East container services, and the Seagirt Marine Terminal is a container facility comprising 270 acres. Rukert Terminals Corporation handles bulk cargo. Consolidation Coal Sales is a coal export terminal occupying 130 acres. There are also terminals at Port Covington (coal and grain), and Curtis Bay (coal). At Sparrows Point, Bethlehem Steel Company operates the largest tidewater ore dock in the world. Foreign Trade Zones No. 63, 73, 74 are included in the Port, the latter of which is located near Dundalk Marine Terminal on 127 acres of land.

Principal imports for the Port of Baltimore are general cargo, petroleum, ores, lumber, and motor vehicles. Exports include general cargoes, grains, coal, and chemicals. Coastwise trade is primarily in petroleum products.

Plans for the Port include deepening of the channel to accommodate the larger vessels now used to move bulk cargoes. Dredging at Dundalk will accommodate larger container vessels. The Maryland Port Administration plans to develop a 350 acre area of Baltimore Harbor into the Masonville Marine Terminal multi-berth container facility.

Reference Publications:

Baltimore Maritime Exchange
Lloyd's Ports of the World
USCG Port Needs Study - Volume II: Appendices, Part 1/August 1991
Port of Baltimore Foreign Commerce Statistical Report 1991
Port of Baltimore Strategic Plan

HAMPTON ROADS

General Information

The Hampton Roads port system, located midway along the Atlantic Coast and at the southern section of the Chesapeake Bay, includes the major ports of Norfolk and Newport News. Other ports within the system include Portsmouth, Chesapeake, Hopewell, and Richmond. Vessels entering from the sea follow a course between the Virginia Capes, across the lower end of Chesapeake Bay, and into the deep waters of Hampton Roads. Two channels extend through the Roads. One follows southward into Norfolk, Portsmouth, and Chesapeake via the Elizabeth River, and one follows westward to Newport News, and then up the James River to the ports of Hopewell and Richmond.

In 1990 exports at Hampton Roads reached 61.1 million tons of cargo, while imports reached 9.4 million tons. This 70.5 million tons of foreign waterborne commerce exceeded every other port in the U.S. in foreign trade for the second year in a row. The 1991 total tonnage figure for Hampton Roads is 73,145,766. Annual vessel arrival figures from 1987 to 1991 show a steady increase from 2,744 to 3,158 over the five years. 1991 was the Port's ninth consecutive year of growth.

Hampton Roads commercial shipping is dominated by colliers, which represent the largest ships moving in the Chesapeake Bay. Roughly half of all U.S. coal exports are shipped from the ports system. In 1990, coal loadings rose to almost 62 million tons. Hampton Roads is expected to experience additional increases in exports due to increased European demand for coal imports.

Since 1983, general cargo shipped through the port system has tripled from 2.5 million tons to 7.6 million tons in 1991. Container traffic volumes are forecast to grow by 65 percent during the 1990s expanding from 13.5 million Twenty-Foot Equivalent Units (TEUs) this year to 22 million TEUs by the year 2000 (Ocean Shipping Consultants).

Principal container handling facilities are at the Newport News Marine Terminal, Norfolk International Terminal, Portsmouth Marine Terminal, Lamberts Point, and Sewells Point Terminal. There are also facilities for handling iron ore, bauxite, ore, and sulphur. Other facilities include a fumigation plant, a defrost plant for meat, and a liquid nitrogen tank for refrigerated containers. Lamberts Point in Norfolk provides berthing space for 17 vessels simultaneously on three piers which handle varied cargoes. There are two major coal terminals at Newport News, and coal piers also at Norfolk. Grain elevators are at both Norfolk and Chesapeake ports. The Elizabeth River Terminals in Chesapeake handle general cargo.

Hampton Roads has plans for a 15 million tons/year coal export facility to accommodate the steady increase in coal export demands. Newport News Marine Terminal expansion projects have increased cargo handling capacity by 275,000 tons. Wharf extensions and dredging for additional ship berthing space at the Portsmouth Marine Terminal will extend cargo handling capacity by 610,000 tons. Norfolk Southern Corporation plans to double the size of the Norfolk International Terminal, and to introduce double stack container trains to Hampton Roads thus linking the area to service to the West Coast, and making it one of the largest intermodal terminals on the East Coast.

Other Ports

The 120 acre Port of **Richmond**, located on both banks of the James River some 84 miles upstream from the Port of Hampton Roads, handled a record 467,293 tons of cargo with a total of 125 vessel calls in 1990-91. Principal imports and exports are tobacco and containerized general cargo. **Norfolk** is the U.S. Navy's largest operating base on the East Coast.

Hampton Roads 1991 Exports (short tons)

Europe	1,643,064
Asia	1,321,974
Mediterranean	393,535
Middle East	233,353
Australia/NZ	132,660
South America	128,004
Africa	119,426
Central America	10,816
Caribbean	9,184
TOTAL	3,992,016

Reference Publications:

Hampton Roads Maritime Association
Lloyd's Ports of the World
NABISS/NV/#1
USCG Port Needs Study - Volume II, Appendices, Part 1/August 1991
Port of Greater Hampton Roads Annual Report 1992
Virginia Maritimer - Jan/Feb 1992
Virginia Port Authority Foreign Trade Annual Reports - 1988-1990

SOUTH CAROLINA

General Information

"The Port of Charleston enhanced its position as a world-class container port in 1991, moving a record 6.3 million tons of containerized cargoes. The specialty ports of Georgetown and Port Royal also continued to make excellent progress, positioning themselves for increased participation in non-container cargoes such as salt, paper, steel, and clay. Some 2 million tons of breakbulk cargoes moved across State Ports Authority facilities in 1991, bringing the total cargo position to 8.3 million tons." *(SCSPA Annual Report)* South Carolina exports increased by 82 percent between 1987 and 1990.

Charleston

The Port of Charleston has container handling facilities at the North Charleston and Wando Terminals. The Port's Columbus Street Terminal has berthing for breakbulk, container, and Ro-Ro vessels. Union Pier Terminal is a breakbulk terminal where mostly forest products are handled. Ro-Ro and passenger vessels can also be accommodated at Union Pier. A portable Ro-Ro ramp is now in operation and can be moved to any terminal within the Port. It is designed to accommodate two vessels simultaneously and has a capacity of 100 tons. For coal export, the Shipyard River Coal Terminal has a maximum throughput of 4,000,000 tons/year. The Port has intermodal yards located adjacent to it. Foreign Trade Zone No. 21 occupies part of the Port.

Statistics for the Port of Charleston as follows: the number of vessels/barges at the Port from 1981 to 1991 has been gradually decreasing and variable from 2,161 to 1,543; the total export tonnage for those same years has been on the rise from 3,696,497 to 7,079,404 tons with imports fluctuating between 1,002,845 and 2,641,162 tons and exports fluctuating between 2,347,801 and 4,880,943 tons. *(SCSPA)*

The Port of Charleston reinvested $22.6 million in 1991 in new facilities and equipment to further improve the efficiency of the port. Completion of the Wando Terminal will add approximately 15 percent to existing container throughput capacity at Charleston. However this $75 to $80 million effort will provide capacity for continual growth only through about 1997. A completely new marine terminal for Charleston, known as Terminal X, is in the planning stages. This terminal may be located on Daniel Island (owned by the Guggenheim Foundation), and is expected to serve South Carolina's needs well into the next quarter-century.

Other Ports

Port Royal is located inland from the Atlantic Ocean, off Port Royal Sound. The ocean entrance to Port Royal Sound is southwest of Charleston and northeast of the Savannah River. The Port has a single marginal concrete berth at present partially under construction which has one modern transit shed, a warehouse, and open land available for outside storage. Principal imports and exports for the Port are calcium stearate, clay, lumber, newsprint, paper rolls, plate glass, and slurry. Plans for the future at Port Royal provide for two additional berths and an expanded, modern warehouse facility, and a yard crane and gantry service for bulk and containerized cargo.

Georgetown is a landlocked port with two docks for bulk and breakbulk cargoes. Imported lumber is the principal commodity. International Salt Co. has a storage and processing facility for evaporated salt. Santee Cement Corp. has a cement discharging terminal at the

dockside. There are also tanker facilities. In 1989 some 56 vessels handled 890,000 tons of cargo at the Port.

Reference Publications:

Lloyd's Ports of the World
South Carolina State Ports Authority Annual Report Fiscal Year 1991

SAVANNAH

Savannah is a natural, landlocked freshwater harbor 18 miles from the Atlantic. Vertical clearance below the Talmadge Memorial bridge may cause ships to consider deballasting. Foreign Trade Zone No. 104 serves the Savannah area.

Major cargoes handled by the Port's facilities include the breakbulk commodities of kaolin clay, steel, linerboard, woodpulp, foodstuffs, machinery, and the liquid bulk commodities of anhydrous ammonia, jet fuels, clay slurry, and vegetable oils. Agricultural tonnage consists of wheat, soybeans, corn, peanut meal, and peanuts. From 1982 to 1992 the Port's deepwater terminals have handled a fairly steady rise in total tonnage handled from 10,975,740 tons to 13,568,908 tons. The number of vessel calls between 1989 - 1992 ranged between 1,496 and 1,659.

The Port of Savannah consists of the Garden City Terminal with its three general cargo berths, Ocean Terminal with ten general cargo berths, and private cargo facilities at the East Coast Terminal. The Port also has a grain elevator, a bulk aragonite unloading facility with conveyor system, a wood chip facility, and berthing space for cement, gypsum, bulk raw sugar, and bulk kaolin commodities. The Garden City liquid bulk facility can load/discharge petroleum products, fats, oils, and molasses. There is also one berth used for discharging molten sulphur.

Improvements to the Port of Savannah include widening of the navigation channel and renovating of the Garden City Container Terminal. Plans for the development of 2,200 acres of land up river from the Garden City Container Terminal, with possibly eight new terminals constructed, are being discussed.

Other Ports

Situated on the Atlantic coast 60 miles south of Savannah, the Port of Brunswick is the home of Foreign Trade Zone No. 144. The principal import is potash, and principal exports are kaolin, grain, wood products, liner board, and wood pulp. The Brunswick Port Authority operates the East River Terminal, a bulk material handling dock with a capacity to accommodate 180,000 tons of cargo, situated 13 miles from the harbor entrance. The Mayor's Point Terminal has five acres of open storage for break bulk cargo, and a petroleum barge loading berth. Ro/Ro facilities are available at the Colonel's Island Terminal. The Port also has a pulp plant dock and chemical docks. In 1989 the Port recorded 192 vessel calls.

Reference Publications:

Georgia Ports Authority
Lloyd's Ports of the World

MIAMI

The Port of Miami covers an area of 600 acres, and is located on two connected, limited access islands -- Dodge Island and Lummus Island -- in protected Biscayne Bay. The Port has vehicular and railway bridge access to the island complex. Dodge Island is the cruise line center, while Lummus Island is the commercial section of the Port.

The Dodge Island complex consists of 12 passenger terminals which serve the 23 home-based cruise ships located at the Port. Regular sailings are to the Bahamas, the Caribbean, and Central and South America. The Port of Miami forecasts that the cruise industry will continue to expand during the next decade and beyond. Dodge Island facilities provide 10 Ro-Ro ramps designed specifically to serve those cruise ships which can carry passenger cars, and/or containerized cargo.

Due to the economic success of the Port's cruise industry, the Port handles only "clean" cargo. Petroleum, and all bulk products, are prohibited from the Port of Miami. Lummus Island Container Terminal has a total berth length of 1,705 miles. Imports include clay, tile and brick, refrigerated fruits and vegetables, coffee, tea, spices, and alcoholic beverages, while exports include commodities such as paper, machinery, auto parts, fresh citrus, and various consumables. Traffic figures for the year 1989 note 1,883 cargo vessels with 2,917,839 tons of cargo handled at the Port, and 1,811 cruise ships with over 3 million passengers.

An expansion plan is underway which includes the construction of two additional passenger terminals. The main channel from the sea lanes to the container berths is to be dredged to enable the Port to handle the largest loaded container vessels, and four Ro-Ro berths are to be added to the Lummus Island complex.

Of greatest impact will be the completion of a five-lane fixed-span bridge (under construction, and already in use) from the mainland to the Port, which will facilitate cargo and passenger traffic to and from the Port. The Port's 26-year old two-lane drawbridge is now outdated. The access bridge, and related roadway enhancements, constitute a $52 million project to ease traffic flow between the Miami mainland and the island seaport. The 65-foot high bridge allows traffic to move without interruption to and from the Port, saving shippers time and money in moving freight.

Long-range plans exist for the construction of a tunnel link to the interstate highway system.

Reference Publications:

Lloyd's Ports of the World
Port of Miami Annual Reports 1990, 1991
Port of Miami Official Directory 1991

TAMPA

Tampa is located in the upper reaches of Tampa Bay over 20 miles from the seaward entrance. The air draught clearance at the Skyway Bridge over the Tampa Bay Channel is 183 feet. In 1988-89, 4,333 vessels with a total of 54,000,000 tons of cargo were handled at the Port.

Petroleum is a principal import. Other principal imports and exports for the Port of Tampa include phosphate and related products, liquid sulphur, bulk cement, fresh fruit and citrus, and anhydrous ammonia.

The Port consists of nine general cargo terminals (also containers), 14 chemical terminals, four cement terminals, five scrap metal facilities, three grain feed elevators, a banana unloading facility, a liquid bulk terminal used primarily for the import of orange juice concentrate, a cattle export facility, 26 berths of tanker terminals, and facilities for the Port's cruise ship industry.

A large general cargo complex is under construction. Future planning includes the development of a downtown cruise terminal complex.

Reference Publications:

Lloyd's Ports of the World
USCG Ports Needs Study - Volume II: Appendices, Part 2/August 1991

NEW ORLEANS

"The Port of New Orleans is situated at the confluence of a gigantic transportation funnel created by the waterway system of the Mississippi River and its tributaries. The Port takes advantage of the nation's inland waterways system and is the main center of barge activity and LASH vessels in the country. The harbor extends into the parishes of Orleans, Jefferson, and St. Bernard. Wharves and facilities are also found along the Mississippi River at Pilot Town, Ostrica, Empire, Port Sulphur, Davant, Myrtle Grove, Alliance, Chalmette, Gretna, Marrero, Westwego, Avondale, Destrehan, Good Hope, Norco, Taft, Gramercy, Convent, Burnside, Donaldsville, Plaquemine, Port Allen, and Baton Rouge." *(Lloyd's)*

The Port of New Orleans consists of over 22 million square feet of cargo-handling area with wharves and terminals spread over 22 miles of waterfront along the Mississippi River, Industrial Canal, and the Mississippi River-Gulf Outlet. There is a total of 110 cargo berths within the port area. Foreign Trade Zone No. 2 occupies 19 acres of space of which approximately 50 percent is shedded. The area is located adjacent to and north of the Napoleon Avenue Terminal. Vessel traffic to the Port must consider ballasting to navigate under bridges enroute to Baton Rouge. Principal imports of the Port include crude petroleum, coffee, iron and steel products, machinery, non-ferrous metals, and petroleum products. Exports include grain, machinery, animal feed, chemicals, petroleum products, and non-ferrous metals. Cargo activity at public facilities from 1985 to 1991 ranged from 16,290,537 to 20,645,244 tons during the seven years.

Construction has begun on a five-year, $200-million capital improvement program that will reshape the Port of New Orleans relative to breakbulk, neobulk, and containerized cargo, including three super terminals at the wharves on the Mississippi River. Two of the terminals - Nashville-Napoleon and Louisiana Avenue - will be multipurpose terminals handling a broad range of cargo. The third, the Harmony Street-First Street Terminal, will be developed to meet the needs of steel and neobulk freight. The $74-million Nashville/Napoleon Multipurpose Terminal is under construction. When complete, it will tie two of the busiest wharves in the Port together, and provide a total of two miles of unbroken wharf, making it one of the longest continuous wharves in the world. At the Harmony/First Street Neobulk-Steel Terminal, construction for a connecting wharf to bridge the gap between the Louisiana and Harmony Street wharves is scheduled. Construction is also slated for tidewater terminal improvements on the Industrial Canal. The Mississippi River channel from the Gulf of Mexico is to be deepened to a depth of 44.5 feet. Future proposals are to further deepen the channel to 49 feet, and eventually to 54 feet as far as Baton Rouge.

Reference Publications:

Lloyd's Port of the World
NABISS/NP/#7
USCG Port Needs Study - Volume 11: Appendices, Part 1/August 1991
Port of New Orleans - 1991 Annual Directory

GALVESTON/HOUSTON

General Information

The Galveston-Houston regional port system includes the Port of Galveston, the neighboring large Port of Houston (including the Houston Ship Channel), as well as the smaller ports of Freeport and Texas City. "The complex is one of the busiest ports in the United States, ranking third (after Valdez and Delaware Bay) in the tonnage of crude oil handled, and second (after New York) in the tonnage of petroleum products." *(Port Needs Study)*

Galveston

Situated at the eastern end of Galveston Island, off the Texas coast, the Port of Galveston has a jetty system consisting of two granite breakwaters which parallel the outer channel and extend across the inner and outer bars and out into the Gulf of Mexico. Port of Galveston wharves are located on the north side of the island.

The Port has changed since the early 1970s. Several docks have been destroyed by fires. Galveston used to be the country's third largest cotton exporter. Other breakbulk commodities were tea, rice, plywood. In 1992, these exports are very limited. The Port has one container terminal with an active fruit trade via Del Monte of bananas and pineapples. Galveston has two major grain (wheat, corn) elevators with a total storage capacity of nearly 9,000,000 bushels. There are 22 shipside warehouses (chiefly used for storing sacked goods and general cargoes), and ten open-dock berths with paved areas. The majority of traffic serving the area carries petroleum or various forms of hazardous cargo.

A highway and rail causeway spans the west end of the channel connecting Galveston to Pelican Island, the Port's oil terminal. Pelican Island receives marine fuels from tankers and distributes it as bunkers directly or by barge. Future development of Galveston calls for construction of a multipurpose two berth breakbulk cargo and cold storage facility on Pelican Island.

Houston

The Port of Houston is situated on the Houston Ship Channel, some 40 plus miles from the Gulf of Mexico. From Bolivar Roads at Galveston Bay the Houston Ship Channel extends inland to the deep-water Houston Turning Basin. Vessels may find ballasting necessary enroute due to bridges.

The Port of Houston complex has over 200 piers and wharves, from the Turning Basin to Morgans Point, near Baytown where the ship channel enters Galveston Bay. Some 60 of these piers handle general cargo. The remainder are specialized wharves and belong to the complex of refineries, chemical plants, steel mills, and other industries that line the Channel. The Foreign Trade Zone No. 84 has 1,500 acres of open land and warehouse space.

The Bayport Industrial Development, a chemical and chemical specialty complex, is one of the largest of its kind in the U.S. At Bayport, a bulk liquid cargo terminal is capable of handling four ocean-going tankers and five barges at once, with a storage capacity of 400,000 barrels, and plans to increase this capacity. The Barbours Cut Terminal is located at the Morgans Point facility. This terminal includes Ro-Ro facilities and four major container wharves. Two more container wharves are to be constructed. Containers are also handled in the Turning Basin area at one public, and several private, container terminals. The bulk terminal at Green's Bayou on the Houston Ship Channel has recently undergone extensive modification. The Port of Houston owns and operates a grain elevator with a capacity of six million bushels. There are also four other privately-operated elevators along the Houston Ship Channel giving the Port a total grain

capacity of more than 30 million bushels. Tanker facilities for handling bulk liquid commodities are numerous at various refineries and manufacturing facilities along the Houston Ship Channel. Tonnage for up to 10,000,000 barrels of crude oil and liquid products can be accommodated. There are six liquified gas terminals within the Port of Houston complex.

The Port plans for an automobile import berth to be created. A new Ro-Ro shed is to be made available which will double the existing storage capacity for heavy marine cargoes. A recent study is in favor of both widening and deepening the Houston Ship Channel.

Other Ports

The Port of **Freeport** is situated at the mouth of the Brazos River (south of Houston). Principal imports and exports include bananas, chemicals, grains, heavy lifts, lumber, pipe, rice, and steel. The Port has modern deep water terminals and a new barge terminal. Dow Chemical Co. operates one dry cargo berth, five oil and chemical docks, and several chemical barge docks Phillips Petroleum Co. operates five oil berths and one barge dock. A recently completed oil and chemical barge dock on Quintana Island with tank storage capacity of 640,000 barrels is operated by Old River Co. Foreign Trade Zone No. 149 has recently been set up and covers over 1950 acres.

Work is underway to deepen the navigation channel and to purchase more waterfront land in an effort to diversify activities. The plan calls for the eventual take-over of three tanker berths currently out on lease, plus a site for the building of a grain elevator as well as container facilities.

Texas City is reached by passing through the jetties protecting the channels leading to Galveston and Houston. The Port has 43 berths, including a bulk cargo handling facility on a 93 acre site, a steel and concrete dry cargo dock, five covered warehouses, 12 berths for tankers, and extensive berthage for barges. Four railways serve the Port, and space is available for future development. The Port's principal imports and exports are oil, oil products, chemicals, and dry bulk commodities. In 1989 vessel numbers reached 1,063 vessels and 6,331 barges, with 48,411,404 tons of cargo handled.

Reference Publications:

Lloyd's Ports of the World
NABISS/NP/#8
USCG Port Needs Study - Volume II: Appendices, Part 1/August 1991

SAN DIEGO

The Port of San Diego, the first U.S. port of call on the West Coast from the Panama Canal, is a center of trade, shipping, commercial fishing, and recreation. It is 14 miles long and covers over 23 square miles of water and land. The Navy, Coast Guard, and Marine Corps occupy and utilize sizeable areas of the Port (the federal government owns substantial portions of the tidelands).

The cruise ship industry plays a large part in the volume of traffic at the Port of San Diego. In season, cruises to the "Mexican Riviera" and a variety of other destinations originate from the cruise ship terminal. Cruise operations increased further in 1991 with the advent of one-day cruises to Ensenada. To accommodate the future growth of the cruise ship industry, the Port of San Diego began planning an expansion of their cruise ship terminals in 1991. Along with the completion of reconstruction of the 75-year old Broadway Pier ($9.5 million renovation), plans are being developed for a sea/land complex. In addition, the Port is generating plans to redevelop the B Street Pier in order to accommodate more and larger cruise ships.

The Tenth Avenue Marine Terminal and the National City Marine Terminal are the two main commercial shipping facilities in San Diego. The Tenth Avenue Marine Terminal is a 96-acre complex. Principal inbound cargoes are general merchandise, fertilizer, canned fish, and newsprint. Cement arrives from Manzanillo and Guaymas. From American Samoa, shipments of tuna arrive on a monthly basis. The steel used to build the new $165 million convention center came through this facility. Major outbound cargoes are corn, wheat, and potash.

The National City Marine Terminal is the largest cargo handling facility in San Diego Bay. Development of the terminal, a 125-acre complex, began in 1968. The principal cargoes at this terminal are vehicles, lumber, and fuel oil. The terminal is the location of one of the largest auto transport facilities on the West Coast. The lumber imported here is generally from the Pacific Northwest.

The Port is seeking additional cargoes to support the local maritime industry. The current auto transport fleet may soon be joined by a fleet of fruit cargo ships. Since 1986-87 the Port has had high expectations for new maritime commerce in the form of such cargoes as refrigerated fruits and commodities. A recent feasibility study reported that San Diego has the potential to attract 30 percent - 40 percent of the total U.S. West Coast market for Chilean fruit, as well as fruit originating from New Zealand, to become a major participant in the growing international fruit trade industry.

Reference Publications:

From Port to Starboard: a guided tour around the Port of San Diego
Lloyd's Ports of the World
NABISS/NP/#11
San Diego Unified Port District

LOS ANGELES/LONG BEACH

General Information

The Los Angeles/Long Beach port complex ranks as the second largest container port in the world. Los Angeles is the leading container port in the United States, and Long Beach is the third largest. NABISS interviewers were told that "tremendous growth is expected here." Forecasts indicate that to meet consumer demand into the 21st century, cargo volume through Los Angeles/ Long Beach is expected to rise to 140 million tons by the year 2020, doubling the current annual throughput.

To meet the needs of the future, the Los Angeles/Long Beach port complex is cultivating trade with bigger ships and more containers. The 2020 Program is a multibillion dollar phased plan of dredging, land filling, and facilities construction which will create the world's largest intermodal transportation hub.

Long Beach

The Port of Long Beach is on the eastern part of San Pedro Bay 25 miles south of the Los Angeles industrial area and adjacent to the Port of Los Angeles. Marine terminals consist of 8.25 miles of berthing space, comprising 67 deepwater berths - 26 in East Basin, 16 in Inner Harbor, 22 in Southeast Basin, and three in West Basin. Long Beach has a channel depth of 70 feet, but some of the inner harbor berths have depths as shallow as 35 feet where deballasting may be necessary.

There are six terminals for container and Ro-Ro facilities. The breakbulk and general cargo terminals handle a wide variety of cargoes, including lumber, plywood, newsprint paper, steel products, fruit, and automobiles. Specialized terminals serve the requirements of dry bulk cargoes, containers, and oil. "Although the emphasis is upon container traffic, Long Beach is rated by the Center for Marine Conservation as the eighth busiest port in the U.S. from the standpoint of moving crude oil. The combined ports have a heavy schedule of tank ships and petroleum product barges." *(Port Needs Study)*

In fiscal 1990-91, Long Beach handled nearly 73 million tons of cargo. Long Beach outdistanced East Coast leader New York/New Jersey in container movements, and is far and away Toyota's primary U.S. port entry. Over the next three decades, Long Beach container cargo is expected to triple. Vessel activity for the Port of Long Beach during the fiscal years 1984/85 to 1991/92 varied between 4,652 and 5,785 vessel calls (this includes tugs and barges but not fishing and pleasure craft). "The U.S. Navy transits to and from Long Beach Naval Station are increasing and add another dimension to overall traffic." *(Port Needs Study)*

Foreign Trade Zone No. 50 is situated in North Long Beach and is operated in conjunction with the Port of Los Angeles. Though the Port may be the largest car importer on the West Coast, the car carriers coming into the Port are of minor importance in the Port's overall picture.

Los Angeles

WORLDPORT LA occupies 7,500 acres and 28 miles of waterfront, and has marine terminals that presently handle more than 60 million metric tons of import and export cargo annually. The greatest increase in West Coast foreign trade (from 1983 to 1990) occurred at the Port, which handled 24.7 million tons in 1990, a 102 percent increase of 12.5 million tons over the seven-year period.

The Port has three distinct sections: the San Pedro District, the Wilmington District, and

the Terminal Island District. The Port now has ten modern container terminals spread out among the three districts. With container throughput for 1991 equaling 2.1 million TEUs, WORLDPORT LA is the busiest container port in the United States. In addition to container traffic and petroleum products, there is a considerable volume of general cargo, including automobiles. Bulk loading and unloading facilities at the San Pedro District handle coal, iron ore, iron pellets, copper and zinc ores, and grain. Dry and liquid bulk throughput for the Port accounted for over 45 percent of the total cargo volume in 1991.

"The U.S. cruise market was one of the Port's success stories in the 1980s and growth shows no signs of tailing off in the 1990s."*(Worldport LA-West Coast Leader)* Projections indicate that the growth of the cruise travel industry will continue through this decade, with 750,000 passengers on 475 ship calls expected by the mid-1990s. The new World Cruise Center is located along the Main Channel, which is a 1,000-foot wide ocean corridor that gives maneuvering room for the largest cruise liners. This facility can accommodate five cruise ships simultaneously. With these facilities in place, WORLDPORT LA expects to maintain its hold as the leading West Coast passenger port.

Reference Publications:

Financial Statement - Worldport LA - Fiscal Year Ending June 30, 1991
Lloyd's Ports of the World
NABISS/NP/#10
USCG Port Needs Study - Volume II: Appendices, Part 1/August 1991
Port of Long Beach Interport Annual 1991
The 2020 Program - Worldport LA's Answer for Tomorrow
Worldport LA Handbook 1992
Worldport LA West Coast Leader - Market Share Analysis 1990

SAN FRANCISCO/OAKLAND

General Information

The major ports of the San Francisco Bay area include San Francisco, Oakland, Sacramento, and Stockton, "The area ranks as the fifth largest port in the U.S. in terms of crude oil handled, and sixth in terms of refined oil." *(Port Needs Study)* Approximately 25 percent of the arrivals in the bay are tankers and more than 10 percent are container ships. Facilities support a wide mix of traffic, ranging from petroleum tankers to passenger vessels.

San Francisco

The Port of San Francisco has 18 maritime piers, including a two-pier passenger terminal, and Foreign Trade Zone No. 3, located on San Francisco's northern waterfront. Container and Ro-Ro facilities include South Terminal with three berths and a 36-acre Intermodal Container Transfer Facility, and North Terminal with seven berths. An automobile terminal at Pier 70 has one berth. In addition, there are 11 breakbulk facilities at the Port. Bulk cargo facilities include one terminal with a grain elevator, and two liquid bulk terminals. Expansion of South Terminal by two container berths is planned, and the Port further hopes to find sites for up to five new container berths.

Oakland

Situated on the mainland side of San Francisco Bay, the Port of Oakland occupies about 20,000 acres of land, stretching along the waterfront for approximately 19 miles. The Port's marine terminal facilities are located in the four areas known as the Outer Harbor, Middle Harbor, Seventh Street, and the Inner Harbor. The Port consists of 29 berths of which 24 serve container, combination container, breakbulk, and Ro-Ro vessels. In 1987, the Port handled 14,176,000 tons of cargo of which 12,360,000 tons was containerized.

The Outer Harbor complex has four terminals with 10 berths, including a multi-purpose general cargo facility for break-bulk, container, and Ro-Ro traffic, and a new intermodal container transfer facility. Between the Outer Harbor and the Seventh Street area is the new Carnation Terminal covering a 30 acre site which accommodates the latest generation of container vessels. The Seventh Street complex has two terminals with eight berths for container freight. The Middle Harbor complex consists of two terminals with a total of six berths. One is a multi-purpose terminal which handles conventional and Ro-Ro vessels, has facilities to accommodate heavy lift and break-bulk cargoes, and provides cold storage. The second terminal is the steel import center for northern California.

Other Ports

The Port of **Sacramento** is situated off San Francisco Bay up the Sacramento River, some 79 miles via the Sacramento Deepwater Ship Channel. Handling grain, rice, and various other bulk commodities, the Port consists of five berths (three wharves, two piers) and two barge slips. A Foreign Trade Zone has been established adjacent to the port. The Sacramento Deepwater Ship Channel is being widened and deepened with completion scheduled for 1994.

The Port of **Stockton** is located 222 miles due east of the Golden Gate Bridge, the entrance to San Francisco Bay. There are three bridges to navigate enroute to Stockton on the 124 mile Stockton Ship Channel. Berthing facilities are available for nine vessels. The Port handles containers, bulk, and breakbulk cargoes, and has one multi-purpose dock for Ro-Ro

facilities. Bulk commodities include grain, fertilizers, cement, coal, coke, sulphur, and molasses. Stockton has pipeline facilities for receiving bulk liquid products from deep-draft tankers to tank farm storage.

Reference Publications:

Lloyd's Ports of the World
USCG Ports Needs Study - Volume II: Appendices, Part 2/August 1991

COLUMBIA RIVER

General Information

"The Columbia River and its tributary, the Willamette River, is the most commercially important U.S. river system emptying into the Pacific Ocean. Deep-draft ships navigate the waterway to Portland and Vancouver, and barge traffic navigates the Columbia River to Pasco and Kennewick, WA some 329 miles from the entrance." *(Lloyd's)* It should be noted that traffic must negotiate bridges in the Portland vicinity. The entire Columbia and Willamette waterway is an important salmon spawning ground.

The major ports of the Columbia and Willamette Rivers, being Astoria, Longview, Portland, and Vancouver, handle some 40 million tons of cargo annually. Exports include logs, lumber and other forest products, grain, flour, chemicals, fruit, fish, general and containerized cargo. Imports are coal, petroleum products, bulk salt, bulk cement, alumina, and general and containerized cargo.

Portland

Situated on the Willamette River, the Port of Portland has five public terminals in operation, encompassing over 17 multipurpose berths for handling container cargo, Ro-Ro cargo, forestry products, and refrigerated cargoes. Also available are warehouse and distribution operations with covered storage space and open area. One terminal is devoted to a grain elevator. Tanker terminals provide 34 berths for the eight oil company operations. All terminals are connected to the railway system. In 1989 9,260,848 tons of cargo were handled by the Port.

Future developments for the waterfront of Portland include the construction of a new automobile dock to accommodate the latest generation of combination auto-container carriers. There are also plans in place to construct more container berths, extra container storage area, and another automobile berth.

Vancouver

Vancouver is situated on the Columbia River upstream of the Willamette River junction. Its facilities include general cargo wharves (four berths), and bulk cargo facilities (one berth), a grain elevator dock (two berths), a cement dock and an aluminum dock (one berth each). There is one privately owned tanker terminal. Automobile carriers and Ro-Ro vessels have a low profile in Vancouver. Three major railroads serve the Port. The Port's principal imports and exports include grain, mineral concentrates, fertilizer, wood products, paper products, steel, automobiles, and livestock. In 1989, 4,161,674 tons of cargo were handled with a total of 338 vessels.

Expansion plans for the Port of Vancouver call for additional storage capacity for dry bulk commodities to be built on a recently acquired 33 acre site. There are also two deep water sites available for development along the navigation channel.

Other Ports

Situated at the mouth of the Columbia River, **Astoria** is the first port of entry on the Columbia River. A landlocked harbor, its container and Ro-Ro terminals are comprised of three piers, with warehousing and open storage areas available. The Port handles such cargoes as logs, woodpulp, newsprint, paper imports and exports, and fuel imports.

Longview is situated 40 miles up the Columbia River. The Port has five deep water berths for containerized cargo handling. Bulk facilities include a grain elevator, a chemical storage facility with 10,000 ton capacity, and a bulk animal feed facility with storage capacity of 20,000 tons. The port is serviced by rail with adjacent warehouses and open dock space. Principal imports include various bulk and general cargoes, while exports consist of logs, lumber and wood products, paper products, grain, and general cargo. Foreign Trade Zone No. 120 is included in the port.

Reference Publications:

Lloyd's Ports of the World
USCG Port Needs Study - Volume II: Appendices, Part 2/August 1991

PUGET SOUND

General Information

Puget Sound is a major inland waterway system serving the U.S. and Canada. The Puget Sound port system includes the ports of Seattle and Tacoma, and the smaller ports of Port Angeles, Port Townsend, Everett, Bellingham, Edmonds, Olympia, and Anacortes. Three U.S. Navy facilities are in the Sound. There are several oil terminals throughout the Puget Sound system, and three major oil refineries. Inbound and outbound traffic is reported by the *Port Needs Study* to be at a rate of approximately 30 ships per day. The area has frequent intra-/interstate barge traffic including those that move large rafts of logs.

Seattle

Located on Puget Sound, Seattle is a nearly landlocked harbor in Elliot Bay. Besides Elliot Bay, there is also an inland harbor area, comprised of the fresh water Lakes Washington and Union, which is connected with Puget Sound by the Lake Washington Ship Canal. Seattle is the major commercial port in the Puget Sound waterway. It handles approximately 1.2 million TEUs/year of container traffic, and also services a mix of bulk and general cargo, including automobiles. Petroleum is limited to refined products in relatively modest amounts. The Port has 20 terminals for general commerce with 58 berths to handle various commodities, container and Ro-Ro facilities covering some 95 acres, tanker terminals with seven berths, and bulk grain loading facilities. Seattle is home to Foreign Trade Zone No. 5.

Principal imports are general cargo and automobiles, while exports include grain and cereals, fish, woodpulp, and waste paper. Though Seattle has little room for further large-scale development, expansion and renovation of the existing auto import and oil rig berthing terminal is planned, in addition to a new passenger terminal.

Tacoma

The Port of Tacoma, situated on Commencement Bay at the south end of Puget Sound, is a natural harbor with facilities which include 34 deep-draft berths located on three waterways. There are seven terminals for container and Ro-Ro cargoes, including the Blair Terminal for log exports which handles over 1,000,000 tons of logs/year, and the Pierce County Terminal, the Port's major vehicle import center. The Port has ore handling facilities (four berths) , a grain facility (one berth), and one oil refinery. Foreign Trade Zone No. 86 covers 638 acres.

Reference Publications:

Lloyd's Ports of the World
Pacific Gateway - Port of Tacoma, Summer 1992
USCG Port Needs Study - Volume II: Appendices, Part 1/August 1991
Port of Seattle 1991 Annual Report
Port of Tacoma Annual Reports 1987-1991
Port of Tacoma Facilities & Services Summary
The Blair Waterway 2010 Plan

ANCHORAGE

Anchorage, with over half of the state's population, is the financial, commercial, and transportation center of Alaska. The 110-acre Port of Anchorage is located one mile north of Anchorage in the upper Cook Inlet. The waterway extends 175 miles from the entrances of Cook Inlet to Anchorage, and is over 60 miles wide at its broadest expanse. Anchorage serves as the primary port of entry and exit for the state's general cargo. In addition to shipping, Anchorage supports offshore oil production/exploration and major fisheries. It is the most northern deep draft port in the United States, and is open year round. Some drift and harbor ice is present during winter months (November through April).

For two decades the Port has experienced significant growth. In 1961, the Port of Anchorage consisted of a single pier which handled 200 tons of cargo a year. The Port's facilities have expanded to include a 2,524-foot dock with modern freight handling systems that currently move over two million tons annually. The Port presently has five terminals which are capable of handling every type of standard cargo vessel: container, Ro-Ro, petroleum and dry bulk, as well as specialized carriers for automobiles, newsprint, and cement. Two of the terminals are specifically designed for accommodating petroleum and the other three handle container, Ro-Ro, and breakbulk cargo.

Total annual tonnage handled those same years steadily climbed from 1,766,590 to 2,312,725 tons - this included petroleum which rose during that time from 304,914 to 925,173 tons. The yearly totals for vessel arrivals from 1986 to 1991 varied between 417 (1989) and 571 (1988).

Expansion of the Port of Anchorage waterfront is in progress at Ship Creek. Development will provide for a multipurpose dock with 900 feet of berth area for cruise ships and other large vessels, and over 30 additional acres for maritime and industrial uses. An additional acquisition includes 1,400 acres of tideland to provide for long-term development. Anchorage has applied to become a Foreign Trade Zone, and storage and transit areas are already designated for this purpose. Long-term facility development targets Fire Island near Anchorage International Airport (this would require bridges to be built), and a new terminal at Point MacKenzie across the Knik Arm from Anchorage, as potential sites for the expanding port.

Reference Publications:

Lloyd's Ports of the World
NABISS/NP/#14
USCG Port Needs Study - Volume II: Appendices, Part 2 /August 1991
Port of Anchorage Annual Tonnage 1982 - 1991
Port of Anchorage Port Facilities
Port of Anchorage Yearly Vessel Arrival Report 1986 - 1991

HAWAIIAN ISLANDS

General Information

By its very nature, Hawaii's history is steeped in its maritime heritage: the Polynesian voyagers were the first to set foot on the Hawaiian Islands; the Western world discovered the islands with Captain James Cook's landing in 1778; the great whaling era of 1820-1860 further populated the islands; the opening of the Panama Canal in 1914 began trade routes to the Far East; the building of the Aloha Tower in 1926, the completion of the then "deluxe" Diamond Head Terminal (Honolulu Harbor's Piers 1 and 2 today) in 1955, and now the Barbers Point Harbor expansion project have brought Hawaii to the 21st century as a recognized port in the world.

Consisting of seven deep-draft harbors and one medium-draft harbor located on five different islands throughout the state, the Hawaiian port system has a growing role in the emerging area of the Pacific. Harbors within the Hawaiian port system include Barbers Point Harbor (Oahu), Hilo Harbor (Hawaii), Honolulu Harbor (Oahu), Kahului Harbor (Maui), Kaunakakai Harbor (Molokai), Kawaihae Harbor (Hawaii), Nawiliwili Harbor (Kauai), and Port Allen (Kauai).

In the fiscal year ending June 30, 1986, there were over 4,300 ship movements throughout the Hawaiian port system. Of these, 1,968 were overseas voyages between Hawaiian ports and ports on either the North American continent, the western rim of the Pacific, or at a distant Pacific island. The Port of Hawaii system handles over 20 million short tons of cargo annually.

Since gaining statehood in 1959, Hawaii's foreign trade has grown by some 4,000 percent from a total of just over $52 million to over $2 billion today. The development of two major oil refineries at Campbell Industrial Park near Barbers Point on West Oahu significantly impacted Hawaii's international trade pattern. Today, more than half of the state's international trade focuses on petroleum products. Crude oil is imported from Indonesia and Australia.

The Port of Hawaii system is the United State's closest major port to the rapidly expanding economies and industries of the Pacific Rim, particularly the Far East. Over 85 percent of Hawaii's $2.1-plus billion in trade is with Pacific Rim nations. Foreign trade is concentrated on Pacific Rim nations which accounted for 89.9 percent Hawaii's imports and 90.7 percent of the state's exports in 1985. More than half of the imports are automobiles with electronic products accounting for much of the balance.

Hawaii plans to promote its location as a mid-Pacific fueling stop for trans-Pacific shipping. By taking on bunkers at Hawaii, shipping lines can carry more paying cargo at relatively little sacrifice in overall sailing time.

Honolulu

Honolulu Harbor, among the 10 largest container handling ports in the U.S., is the major commercial harbor of the Hawaiian port system. Containerships and tankers, inter-island and ocean-going barges, auto carriers, and bulk cargo ships are all seen in Honolulu Harbor on a day-to-day basis. Bulk cargo imports and exports consist of such commodities as pineapple, sugar, grain, molasses, scrap metal, concrete aggregate, sand, and coal. Hawaii's Foreign-Trade Zone No. 9, located at Pier 2 in Honolulu Harbor, offers more than 300,000 square feet of warehouse, office, and exhibition space, and in 1987 was expanded to include over 1,050 acres of land within the boundaries of both the Barbers Point deep-draft harbor and Campbell Industrial Park (oil refinery).

Barbers Point

A new harbor, the second deep-draft commercial harbor of Oahu, is now under construction and already in use at Barbers Point Harbor, west of Honolulu Harbor. The first building phase of the harbor was completed in 1985 with a 92-acre harbor basin and entrance channel. The 38-foot deep harbor has some 4,700 feet of wave absorbers, berthing areas, and navigation aids. A master plan provides for anticipated growth through the year 2010. Future development calls for a 1,600-foot pier, a container yard and bulk cargo facilities, storage areas, a back-up yard and myriad ship support services.

Other Harbors

Hilo Harbor is Hawaii's second largest commercial harbor. It provides a wide range of maritime facilities and services and is the major distribution center for the "Big Island." An expansion program is in progress which will improve and expand both cargo and cruise ship facilities. **Kawaihae Harbor** is the second deep-draft harbor on the "Big Island" and handles both overseas and inter-island cargo. As a port it has ample room for future expansion, and is strategically located to play a bigger role in the proposed development of West Hawaii. **Kahului Harbor** is the only deep-draft harbor for the island of Maui, and provides a complete range of maritime services and facilities to meet the island's needs. The harbor is a regular stop for passenger cruise ships. The other three harbors in the Hawaii port system, **Kaunakakai Harbor**, **Nawiliwili Harbor**, and **Port Allen**, are quite small but all have facilities for handling shipping and cruise line vessels. The United States Navy base at **Pearl Harbor**, some six nautical miles west of Honolulu Harbor, is closed to commercial vessel traffic.

Reference publications:

Lloyd's Ports of the World
NABISS/NP/#12
Port Hawaii Handbook 1988-1989